

**PRAIRIE VIEW A&M UNIVERSITY
ROY G. PERRY COLLEGE OF ENGINEERING
DEPARTMENT OF MECHANICAL ENGINEERING
MCEG 3101- Measurement and Instrumentation Laboratory
FALL 2021**

- I. COURSE DESCRIPTION IN ABET FORMAT**
- II. ASSESSMENT RESULTS FOR CURRENT AND PAST THREE PERIODS**
 - Program Outcomes Assessed in Course**
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- III. TESTS**
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 - Original Test Questions & Master Solution/grading scheme used**
(Summary of topics can be a separate page or include on the assignment itself)
 - Above Average (Graded original work)**
 - Average (Graded original work)**
 - Below Average (Graded original work)**
- IV. QUIZZES**
 - Summary of Topics covered by Quiz**
 - Original Quiz Questions & Master Solution/grading scheme used**
 - Above Average (Graded original work)**
 - Average (Graded original work)**
 - Below Average (Graded original work)**
- V. LABORATORY REPORTS**
 - Summary of Topics covered by Lab**
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 - Above Average (Graded original work)**
 - Average (Graded original work)**
 - Below Average (Graded original work)**
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 - Instructions and Grading Scheme**
 - Above Average (Graded original work)**
 - Average (Graded original work)**
 - Below Average (Graded original work)**

I.

Course Description in ABET Format

MECHANICAL ENGINEERING DEPARTMENT

MCEG3101 Measurement and Instrumentation Laboratory

- | | |
|--|--|
| 1. Course number and name: | MCEG 3101 Measurement and Instrumentation Laboratory |
| 2. Credits and contact hours: | 1 credit hour |
| 3. Instructor's or course coordinator's name: | Dr. Mingli Han |
| 4. Text book: Title: | Measurement Laboratory Manual |
| Author: | Paul. Biney |
| Publisher, Year & Edition: | 2 nd edition |
| a. Other Supplemental material | Experimental Methods for Engineers by J. P. Holman, 7th Edition, McGraw Hill, 2001 |
| 5. Specific course information | |
| a. Brief description of the content of the course (catalog description) | Credit 1 semester hour. The scope of this course includes fundamentals in measurement theory, statistical analysis of experimental data, uncertainty, accuracy assessments, calibration techniques and robotics. The course includes the use and applications of instruments for measuring area, pressure, time, speed, temperature, strain, hardness, and deflection. |
| b. Prerequisites or Co-requisites | PHYS 2513, PHYS 2511, PHYS 2521 |
| c. *Indicate whether a required, elective, or selected elective (as per definition provided) course in the program | Required |

- | | |
|---|---|
| 6. a. Specific goals for the course specific outcomes of instruction (e.g., The student will be able to explain the significance of current research about a particular topic.) | b. Explicitly indicate which of the student outcomes listed in Criterion 3 or any other outcomes are addressed by the course. |
|---|---|

Students will be able to:

The specific goals for the course specific outcomes listed on the left column will address the following student learning outcomes:

1. Understand fundamentals in measurement theory, statistical analysis of experimental data, uncertainty, accuracy assessments, and calibration techniques

2. Use instruments for measuring area, pressure, time, speed, temperature, strain,

Outcome 6

An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions (including use

hardness, and deflection	of the techniques, skills, and modern engineering tools necessary for engineering practice)
3. Analyze experimental data, interpret experimental results and prepare scientific reports.	
4. Understand the concept of life-long learning	Outcome 7 An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.
7 Brief list of topics to be covered	Experiment 1: Statistical Analysis of Experimental Data: Length measurement with Micrometer (2 classes) Experiment 2: Statistical Analysis of Experimental Data: (1) Length measurement with Vernier Caliper. (2) Area measurement using a Planimeter. (2 classes) Experiment 3: Pressure Gauge Calibration using Dead Weight Tester (2 classes) Experiment 4: Statistical Analysis of Experimental Data: Local gravitational acceleration measurement using a simple pendulum (2 classes) Experiment 5: Strain Measurement Using Strain Gauge (2 classes) Experiment 6: Sonar Sensor Calibration (2 classes)

***Required** courses are required of all students in the program, **elective** courses (often referred to as open or free electives) are optional for students, and **selected elective** courses are those for which students must take one or more courses from a specified group

II ASSESSMENT RESULTS FOR CURRENT AND PAST THREE PERIODS

Program Outcomes Assessed in this course

Outcome 6:

An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions (including use of the techniques, skills, and modern engineering tools necessary for engineering practice).

Outcome 7:

An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

Assessment Summary of Class Semester Averages for Outcomes (Fall 2017 to Fall 2020 Semester)

Outcomes	6	7
Semester	Semester Class Average (%)	Semester Class Average (%)
Fall 2021		82.5
Spring 2021	87.1	
Fall 2020		81.1
Spring 2020	83.4	
Fall 2019		81.7
Spring 2019	81.1	
Fall 2018		78.8
Spring 2018	79.7	
Fall 2017		91.4
Spring 2017	89.6	
Comments on Trend of Data (Improving or deteriorating)	The average for this outcome is improving.	The average for this outcome has been stabilized at above 80.

*Expected Semester Class Average = 70% (or as defined by the program)

Ideal Semester Class Average = 75% (or as defined by the program)

End of Semester Course Assessment Reports Fall 2021 and Last Three Assessment Periods.

Each summary contains the following Information

1. Performance Statistics

- Total number of students in class
- The class average performance (**stated as %**) in each course outcome assessed in this class and the **two previous times course was assessed**.
- The acceptable class average for the class in each outcome area as set by your Department.
- Percentage of students who scored below the expected average in each outcome.

2. Implementation Summary

- Brief summary of plans implemented during the semester based on last assessment report

3. Perceived Problems

- Instructor's critical **evaluation** of perceived problems that affected students' performance. **Realistic problems should be identified throughout the semester and summarized in this section of the report.**

4. New Plans for Addressing Problems

- Instructor's plans for addressing the perceived problems the next time the class is taught. **These should be specific enough for another instructor to implement. Most of these should be things that, you, the instructor can implement to help students to improve. Be creative.**

5. Overall Trend over last three assessment periods

- Instructors summary of overall performance trend for each outcome measured over the last three periods.

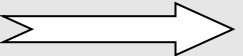
5. Were Expectations Met?

- Answer **YES** if the **class average was above the expected average** and the **stated percentage of students** scored at or above the expected average, else answer **NO**.

Table 2.1 END OF SEMESTER COURSE OUTCOME ASSESSMENT REPORT
MCEG3101- MEASUREMENT AND INSTRUMENTATION LABORATORY
FALL 2021 SEMESTER

Report Prepared by: Dr. Mingli Han

Report Date: December 13, 2021

Semester	Analysis Type	Number of Students	Outcome 7 An ability to acquire and apply new knowledge as needed, using appropriate learning strategies			
			Expected Average	Expected Percent of students at or above average	Class Average	% Students Above Expected Average
Fall 2021	Direct	16	70	70	82.5	75
Fall 2020	Direct	17	70	70	79.1	76.5
Fall 2019	Direct	14	70	70	83.5	92.8
Fall 2018	Direct	14	70	70	78.8	78.6
Implementation Summary		Students were made aware of the importance of life-long learning in the beginning of the course. Resources outside of the classroom are identified and made available to students.				
Perceived Problems		Students are not aware of the importance of life-long learning assignments. Students lack the motivation to find answers to problems that are not discussed in the classroom.				
Plans for Addressing Problems		The following is recommended for implementation: The importance of life-long learning assignments is emphasized on the first day of the class and also the time when the assignments are assigned. To design the assignment associated with the recent technology trend. Students are more motivated when they find the knowledge of the assignment is interesting.				
Overall Trend over Periods		Students' performance is not as good as the previous semester.				
Were Expectations Met?	Average ≥ 70		YES			

MEASUREMENT AND INSTRUMENTATION LABORATORY FALL 2021

MIDTERM EXAM

TOPICS COVERED IN MIDTERM EXAM

Midterm exam covered the following topics:

- Using Excel to do statistical analysis, including
- 1. Mean
- 2. Mean deviation
- 3. Standard deviation
- 4. Covariance
- 5. Plot histogram together with error bar to indicate mean and standard deviation

**SAMPLE MIDTERM EXAM QUESTIONS, SOLUTION,
AND GRADING SCHEME FOR MIDTERM EXAM**

MCEG 3101 Measurement and Instrumentation Laboratory

Midterm Exam

Duration: upload the Excel file in 40 mins

Theory

Statistical Analysis of Experimental Data

In many situations, it is necessary to conduct several set of experiments to ensure that the statistical accuracy of the results can be determined. A number of statistical parameters are needed to determine the statistical accuracy of the experimental results. The statistical parameters to be discussed in this section include the mean, the deviation of each data from the mean, the average deviation, and the standard deviation or the root mean square deviation.

The Mean: The mean x_m , of a set of n data in which each data is represented by x_i ($i=1$ to n) is given by

$$x_m = \frac{1}{n} \sum_{i=1}^n x_i \quad (1)$$

The Deviation: The deviation d_i of a set of n data in which each data is represented by x_i ($i=1$ to n) is given by

$$d_i = x_i - x_m \quad (2)$$

Note that the average of the deviations of all the data is zero since the sum of the deviation is zero.

The Mean Deviation: The average of the absolute values of the deviations is however not zero, and is given by

$$\left| \bar{d}_i \right| = \frac{1}{n} \sum |x_i - x_m| \quad (3)$$

The Standard Deviation: The standard deviation is also known as the root mean square deviation. It is one of the most important statistical parameters that is used to ascertain the accuracy as well as the confidence one will have in the value of the measured data. The standard deviation for a very large set of data is given by

$$\sigma = \left[\frac{1}{n} \sum_{i=1}^n (x_i - x_m)^2 \right]^{1/2} \quad (4)$$

When the number of data is not large (less than 20 for example), the sample standard deviation is given by

$$\sigma = \left[\frac{\sum (x_i - x_m)^2}{n - 1} \right]^{1/2} \quad (5)$$

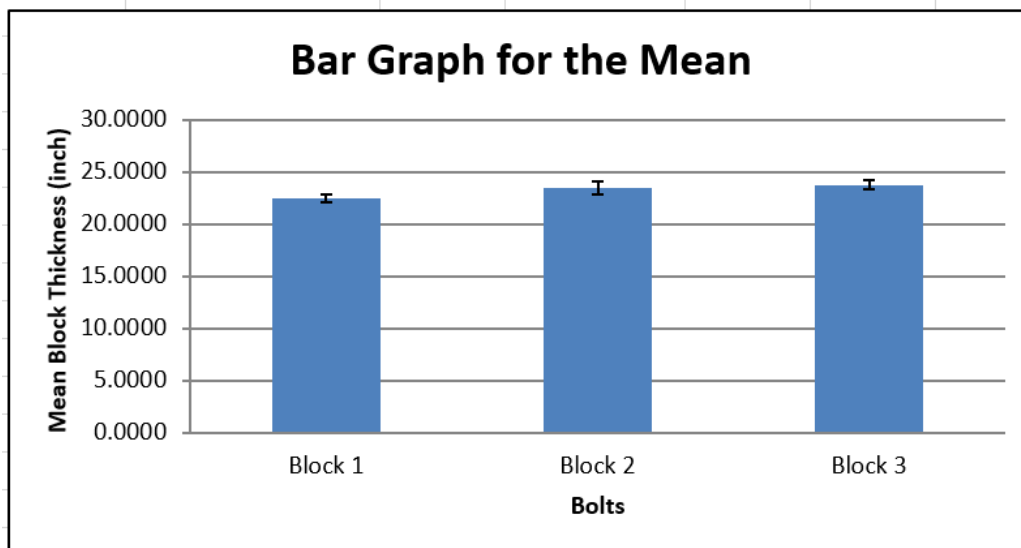
The Covariance: COV=Standard Deviation/Mean

For this exam you can demonstrate your understanding of the statistical analysis discussed in the theory using Excel. However, you are not allowed to use the built-in functions to compute any of the statistical variables in the theory section.

- [illegible]

Name	Block 1	d	d ^2	Block 2	d	d ^2	Block 3	d	d ^2
	21.45	1.0338E+00	1.0688E+00	23.08	3.7905E-01	1.4368E-01	23.38	3.7905E-01	1.4368E-01
	22.45	3.3810E-02	1.1431E-03	23.20	2.5905E-01	6.7106E-02	23.24	5.1905E-01	2.6941E-01
	22.39	9.3810E-02	8.8002E-03	23.52	6.0952E-02	3.7152E-03	23.04	7.1905E-01	5.1703E-01
	22.60	1.1619E-01	1.3500E-02	23.50	4.0952E-02	1.6771E-03	23.46	2.9905E-01	8.9429E-02
	22.42	6.3810E-02	4.0717E-03	23.52	6.0952E-02	3.7152E-03	23.82	6.0952E-02	3.7152E-03
	22.14	3.4381E-01	1.1820E-01	23.50	4.0952E-02	1.6771E-03	23.34	4.1905E-01	1.7560E-01
	22.79	3.0619E-01	9.3753E-02	23.39	6.9048E-02	4.7676E-03	23.81	5.0952E-02	2.5961E-03
	22.61	1.2619E-01	1.5924E-02	23.34	1.1905E-01	1.4172E-02	24.62	8.6095E-01	7.4124E-01
	22.39	9.3810E-02	8.8002E-03	22.60	8.5905E-01	7.3796E-01	23.79	3.0952E-02	9.5805E-04
	22.40	8.3810E-02	7.0240E-03	23.39	6.9048E-02	4.7676E-03	23.54	2.1905E-01	4.7982E-02
	22.72	2.3619E-01	5.5786E-02	24.38	9.2095E-01	8.4815E-01	24.62	8.6095E-01	7.4124E-01
	22.28	2.0381E-01	4.1538E-02	22.52	9.3905E-01	8.8181E-01	24.02	2.6095E-01	6.8096E-02
	22.20	2.8381E-01	8.0548E-02	23.80	3.4095E-01	1.1625E-01	23.22	5.3905E-01	2.9057E-01
	22.60	1.1619E-01	1.3500E-02	23.90	4.4095E-01	1.9444E-01	23.90	1.4095E-01	1.9868E-02
	22.84	3.5619E-01	1.2687E-01	24.02	5.6095E-01	3.1467E-01	23.84	8.0952E-02	6.5533E-03
	22.22	2.6381E-01	6.9595E-02	23.04	4.1905E-01	1.7560E-01	23.80	4.0952E-02	1.6771E-03
	23.20	7.1619E-01	5.1293E-01	24.12	6.6095E-01	4.3686E-01	24.42	6.6095E-01	4.3686E-01
	22.18	3.0381E-01	9.2300E-02	24.32	8.6095E-01	7.4124E-01	23.58	1.7905E-01	3.2058E-02
	22.94	4.5619E-01	2.0811E-01	23.84	3.8095E-01	1.4512E-01	24.14	3.8095E-01	1.4512E-01
	23.30	8.1619E-01	6.6617E-01	23.64	1.8095E-01	3.2744E-02	23.94	1.8095E-01	3.2744E-02
	22.04	4.4381E-01	1.9697E-01	22.02	1.4390E+00	2.0709E+00	23.42	3.3905E-01	1.1495E-01
SUM	472.16	6.4914286	3.404295238	492.64	9.1028571	6.940981	498.94	7.2228571	3.881381
N	21	21	21	21	21	21	21	21	21
Mean	22.48381		0.162109297	23.45905		0.3305229	23.75905		0.1848277
Mean Deviation		0.3091156			0.4334694			0.3439456	
SDV			0.402627988			0.5749112			0.4299159

	Block 1	Block 2	Block 3
mean, X_m	22.4838	23.4590	23.7590
Mean Deviation, d_m	0.3091	0.4335	0.3439
SDV, σ	0.4026	0.5749	0.4299
COV	0.0000	0.0000	0.0000



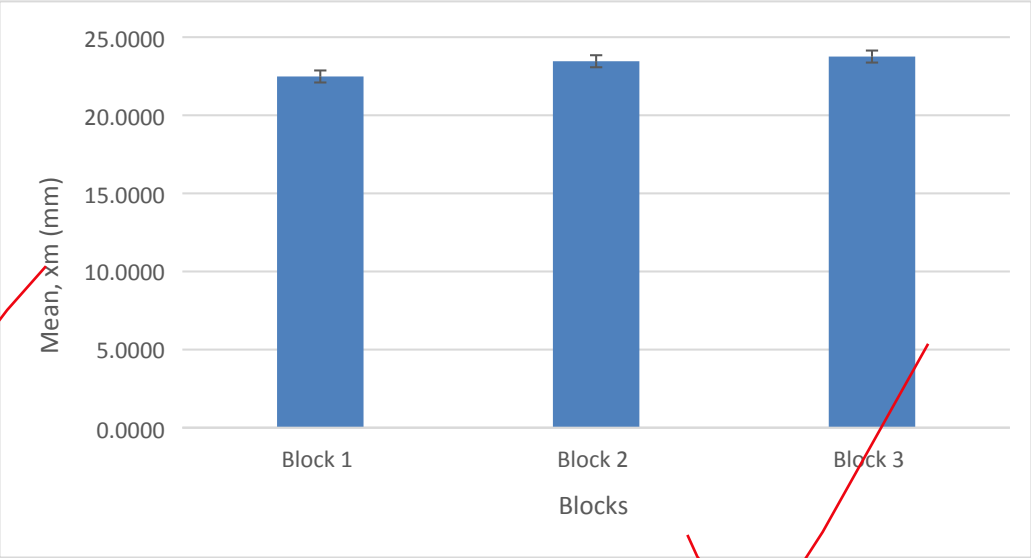
ABOVE AVERAGE

(Except Sum function, please do not use other embeded function in Excel)

	Block 1 (mm)	d	d ^2	Block 2(mm)	d	d ^2	Block 3 (mm)	d	d ^2
	21.45	1.0338E+00	1.0688E+00	23.08	3.7905E-01	1.4368E-01	23.38	3.7905E-01	1.4368E-01
	22.45	3.3810E-02	1.1431E-03	23.20	2.5905E-01	6.7106E-02	23.24	5.1905E-01	2.6941E-01
	22.39	9.3810E-02	8.8002E-03	23.52	6.0952E-02	3.7152E-03	23.04	7.1905E-01	5.1703E-01
	22.60	1.1619E-01	1.3500E-02	23.50	4.0952E-02	1.6771E-03	23.46	2.9905E-01	8.9429E-02
	22.42	6.3810E-02	4.0717E-03	23.52	6.0952E-02	3.7152E-03	23.82	6.0952E-02	3.7152E-03
	22.14	3.4381E-01	1.1820E-01	23.50	4.0952E-02	1.6771E-03	23.34	4.1905E-01	1.7560E-01
	22.79	3.0619E-01	9.3753E-02	23.39	6.9048E-02	4.7676E-03	23.81	5.0952E-02	2.5961E-03
	22.61	1.2619E-01	1.5924E-02	23.34	1.1905E-01	1.4172E-02	24.62	8.6095E-01	7.4124E-01
	22.39	9.3810E-02	8.8002E-03	22.60	8.5905E-01	7.3796E-01	23.79	3.0952E-02	9.5805E-04
	22.40	8.3810E-02	7.0240E-03	23.39	6.9048E-02	4.7676E-03	23.54	2.1905E-01	4.7982E-02
	22.72	2.3619E-01	5.5786E-02	24.38	9.2095E-01	8.4815E-01	24.62	8.6095E-01	7.4124E-01
	22.28	2.0381E-01	4.1538E-02	22.52	9.3905E-01	8.8181E-01	24.02	2.6095E-01	6.8096E-02
	22.20	2.8381E-01	8.0548E-02	23.80	3.4095E-01	1.1625E-01	23.22	5.3905E-01	2.9057E-01
	22.60	1.1619E-01	1.3500E-02	23.90	4.4095E-01	1.9444E-01	23.90	1.4095E-01	1.9868E-02
	22.84	3.5619E-01	1.2687E-01	24.02	5.6095E-01	3.1467E-01	23.84	8.0952E-02	6.5533E-03
	22.22	2.6381E-01	6.9595E-02	23.04	4.1905E-01	1.7560E-01	23.80	4.0952E-02	1.6771E-03
	23.20	7.1619E-01	5.1293E-01	24.12	6.6095E-01	4.3686E-01	24.42	6.6095E-01	4.3686E-01
	22.18	3.0381E-01	9.2300E-02	24.32	8.6095E-01	7.4124E-01	23.58	1.7905E-01	3.2058E-02
	22.94	4.5619E-01	2.0811E-01	23.84	3.8095E-01	1.4512E-01	24.14	3.8095E-01	1.4512E-01
	23.30	8.1619E-01	6.6617E-01	23.64	1.8095E-01	3.2744E-02	23.94	1.8095E-01	3.2744E-02
	22.04	4.4381E-01	1.9697E-01	22.02	1.4390E+00	2.0709E+00	23.42	3.3905E-01	1.1495E-01
SUM	472.16	6.49	3.40	492.64	9.10	6.94	498.94	7.22	3.88
N	21	21	21	21	21	21	21	21	21
Mean	22.48			23.46			23.76		
Mean Deviation		3.0912E-01	1.6211E-01		4.3347E-01	3.3052E-01		3.4395E-01	1.8483E-01
SDV			0.402627988			0.57491121			0.42991588

The significance of the mean is that being the average of the data collected so there is an accurate number, and the mean is used to determine the standard deviation which ensures an even more accurate calculation in a set of data. The results prove that the students measurements are pretty accurate and close to each other. No outliers are present either.

	Block 1	Block 2	Block 3
mean, X_m	22.4838	23.4590	23.7590
Mean Deviation, d_m	0.3091	0.4335	0.3439
SDV, σ	0.4026	0.5749	0.4299
COV			



AVERAGE

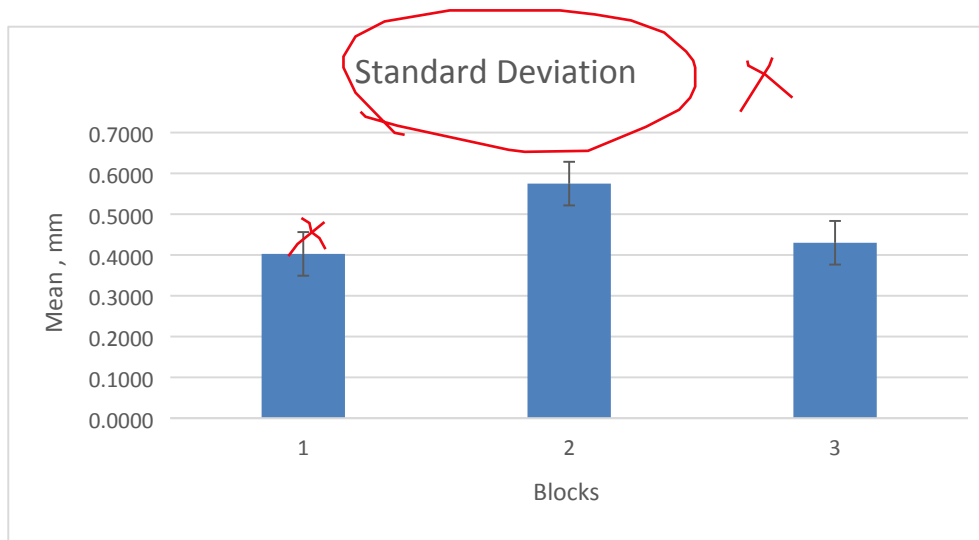
(Except Sum function, please do not use other embeded function in Excel)

Devan Mitchell	Block 1 (mm)	d	d ^2	Block 2(mm)	d	d ^2	Block 3 (mm)	d	d ^2
	21.45	1.03380952	1.068762132	23.08	0.3790476	0.143677098	23.38	0.37904762	0.1436771
	22.45	0.03380952	0.001143084	23.20	0.2590476	0.067105669	23.24	0.51904762	0.2694104
	22.39	0.09380952	0.008800227	23.52	0.0609524	0.003715193	23.04	0.71904762	0.5170295
	22.60	0.11619048	0.013500227	23.50	0.0409524	0.001677098	23.46	0.29904762	0.0894295
	22.42	0.06380952	0.004071655	23.52	0.0609524	0.003715193	23.82	0.06095238	0.0037152
	22.14	0.34380952	0.118204989	23.50	0.0409524	0.001677098	23.34	0.41904762	0.1756009
	22.79	0.30619048	0.093752608	23.39	0.0690476	0.004767574	23.81	0.05095238	0.0025961
	22.61	0.12619048	0.015924036	23.34	0.1190476	0.014172336	24.62	0.86095238	0.741239
	22.39	0.09380952	0.008800227	22.60	0.8590476	0.737962812	23.79	0.03095238	0.000958
	22.40	0.08380952	0.007024036	23.39	0.0690476	0.004767574	23.54	0.21904762	0.0479819
	22.72	0.23619048	0.055785941	24.38	0.9209524	0.848153288	24.62	0.86095238	0.741239
	22.28	0.20380952	0.041538322	22.52	0.9390476	0.881810431	24.02	0.26095238	0.0680961
	22.20	0.28380952	0.080547846	23.80	0.3409524	0.116248526	23.22	0.53904762	0.2905723
	22.60	0.11619048	0.013500227	23.90	0.4409524	0.194439002	23.90	0.14095238	0.0198676
	22.84	0.35619048	0.126871655	24.02	0.5609524	0.314667574	23.84	0.08095238	0.0065533
	22.22	0.26380952	0.069595465	23.04	0.4190476	0.175600907	23.80	0.04095238	0.0016771
	23.20	0.71619048	0.512928798	24.12	0.6609524	0.43685805	24.42	0.66095238	0.436858
	22.18	0.30380952	0.092300227	24.32	0.8609524	0.741239002	23.58	0.17904762	0.032058
	22.94	0.45619048	0.208109751	23.84	0.3809524	0.145124717	24.14	0.38095238	0.1451247
	23.30	0.81619048	0.666166893	23.64	0.1809524	0.032743764	23.94	0.18095238	0.0327438
	22.04	0.44380952	0.196966893	22.02	1.4390476	2.07085805	23.42	0.33904762	0.1149533
SUM	472.16	6.49	3.40	492.64	9.10	6.94	498.94	7.22	3.88
N	21	21	21	21	21	21	21	21	21
Mean	22.48380952	0.30911565	0.162109297	23.45904762	0.4334694	0.330522902	23.75904762	0.34394558	0.1848277
Mean Deviation									
SDV			0.402627988			0.574911213			0.4299159

	Block 1	Block 2	Block 3
mean, $\bar{X}_m$	22.4838	23.4590	23.7590
Mean Deviation, d_m	0.3091	0.4335	0.3439
SDV, σ	0.4026	0.5749	0.4299
COV			

miss discussion

should plot the mean values



BELOW AVERAGE

(Except Sum function, please do not use other embeded function in Excel)

	Block 1 (mm)	d	d ^2	Block 2(mm)	d	d ^2	Block 3 (mm)	d	d ^2
	21.45	1.0696E+00	1.1440E+00	23.08	3.7905E-01	1.4368E-01	23.38	3.7905E-01	
	22.45	6.9595E-02	4.8435E-03	23.20	2.5905E-01	6.7106E-02	23.24	2.3240E+01	
	22.39	1.2960E-01	1.6795E-02	23.52	6.0952E-02	3.7152E-03	23.04	2.3040E+01	
	22.60	8.0405E-02	6.4649E-03	23.50	4.0952E-02	1.6771E-03	23.46	2.3460E+01	
	22.42	9.9595E-02	9.9192E-03	23.52	6.0952E-02	3.7152E-03	23.82	2.3820E+01	
	22.14	3.7960E-01	1.4409E-01	23.50	4.0952E-02	1.6771E-03	23.34	2.3340E+01	
	22.79	2.7040E-01	7.3119E-02	23.39	6.9048E-02	4.7676E-03	23.81	2.3810E+01	
	22.61	9.0405E-02	8.1730E-03	23.34	1.1905E-01	1.4172E-02	24.62	2.4620E+01	
	22.39	1.2960E-01	1.6795E-02	22.60	8.5905E-01	7.3796E-01	23.79	2.3790E+01	
	22.40	1.1960E-01	1.4303E-02	23.39	6.9048E-02	4.7676E-03	23.54	2.3540E+01	
	22.72	2.0040E-01	4.0162E-02	24.38	9.2095E-01	8.4815E-01	24.62	2.4620E+01	
	22.28	2.3960E-01	5.7406E-02	22.52	9.3905E-01	8.8181E-01	24.02	2.4020E+01	
	22.20	3.1960E-01	1.0214E-01	23.80	3.4095E-01	1.1625E-01	23.22	2.3220E+01	
	22.60	8.0405E-02	6.4649E-03	23.90	4.4095E-01	1.9444E-01	23.90	2.3900E+01	
	22.84	3.2040E-01	1.0266E-01	24.02	5.6095E-01	3.1467E-01	23.84	2.3840E+01	
	22.69	1.6821E-01	2.8296E-02	23.04	4.1905E-01	1.7560E-01	23.80	2.3800E+01	
	22.72	2.0186E-01	4.0746E-02	24.12	6.6095E-01	4.3686E-01	24.42	2.4420E+01	
	22.76	2.3550E-01	5.5460E-02	24.32	8.6095E-01	7.4124E-01	23.58	2.3580E+01	
	22.79	2.6914E-01	7.2438E-02	23.84	3.8095E-01	1.4512E-01	24.14	2.4140E+01	
	22.82	3.0279E-01	9.1679E-02	23.64	1.8095E-01	3.2744E-02	23.94	2.3940E+01	
	22.86	3.3643E-01	1.1318E-01	22.02	1.4390E+00	2.0709E+00	23.42	2.3420E+01	
SUM	472.91	5.1127E+00	2.1492E+00	492.64	9.1029E+00	6.9410E+00	498.94		
N	21	21	21	21	21	21	21		
Mean	22.5195524	2.4346E-01	1.0234E-01	23.45904762	4.3347E-01	3.3052E-01	23.75904762		
Mean Deviation									
SDV									

missing discussion and chart.

	Block 1	Block 2	Block 3
mean, X_m			
Mean Deviation, d_m			
SDV, σ			
COV			

MEASUREMENT AND INSTRUMENTATION LABORATORY FALL 2021

FINAL EXAM

TOPICS COVERED IN FINAL EXAM

Final exam covered the following topics:

- Using Engineering Equation Solver (EES) to do statistical analysis, including
1. Mean
 2. Implement engineering equations
 3. Set up parametric table to solve equations in batch
 4. Plot dependent variable vs independent variable
 5. Perform linear regression and identify the statistics of the fitting and slope

**SAMPLE FINAL EXAM QUESTIONS, SOLUTION,
AND GRADING SCHEME FOR FINAL EXAM**

MCEG 3101 Measurement and Instrumentation Laboratory

Final Exam

This is a close book, close notes exam

Duration: 14:00 – 14:50

Theory:

Sonar is a technique that uses sound propagation to navigate, communicate with or detect objects on or under the surface of the water.

Active sonar sensors are fitted with an emitter that generates ultrasonic waves and a receiver that captures them after hitting a target. The voltage signal generated from the sonar sensor is proportional to the distance between the target and the sonar sensor. As the target moving away from the sonar sensor, the measured voltage increases.

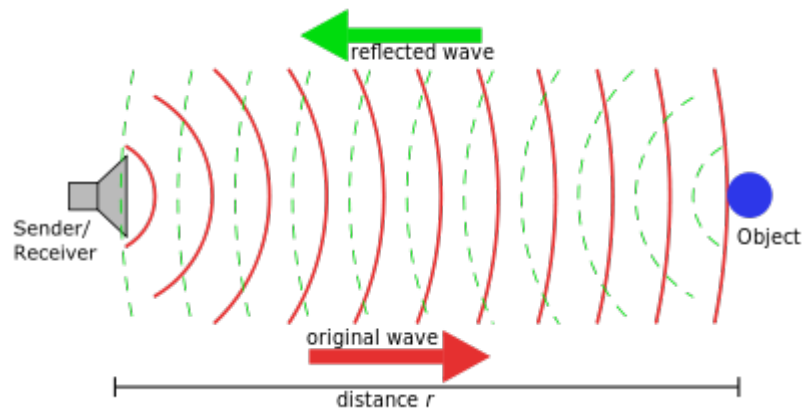


Figure 1 principle of an active sonar (from <https://en.wikipedia.org/wiki/Sonar>).

A sturdy piece of cardboard can be used as a target to calibrate the sonar sensor. Begin with the target close to the sonar sensor and slowly move it further away from the sensor. When the target is set at one position, measure the actual distance between the target and the sensor 5 times, and record the corresponding voltage from the sonar sensor. Repeat for different target positions and summarize in Table 1.

Table1 Collected data for sonar sensor calibration.

	Actual distance between the target and the sensor (in)	Sensor Measurement (V)
Nominal distance = 7	S1 = 6.7	V1 = 0.23
	S2 = 6.4	V2 = 0.27
	S3 = 7.1	V3 = 0.25
	S4 = 6.7	V4 = 0.25
	S5 = 7.3	V5 = 0.23
Nominal distance = 14	S1 = 14.7	V1 = 0.33
	S2 = 13.8	V2 = 0.38
	S3 = 14.1	V3 = 0.39
	S4 = 13.9	V4 = 0.38
	S5 = 13.7	V5 = 0.35
Nominal distance = 22	S1 = 21.5	V1 = 0.65
	S2 = 22.0	V2 = 0.65
	S3 = 22.1	V3 = 0.72
	S4 = 21.9	V4 = 0.69
	S5 = 21.1	V5 = 0.68

Analysis and Results:

1. Use EES to calculate the average of the Actual Distance S and Sensor Measurement V for each nominal distance.
2. Use EES to calculate the standard deviation of Actual Distance σ_s and Sensor Measurement σ_v for each nominal distance. ($\sigma = \left[\frac{\sum (x_i - x_m)^2}{n-1} \right]^{1/2}$)
3. Create a parametric table in EES with the columns S1, S2, S3, S4, S5, V1, V2, V3, V4, V5, S, V, σ_s , σ_v .
4. Plot V versus S. Set the vertical axis to V, and horizontal axis to S.
5. Use EES to fit the best straight line through the points.
6. Plot the equation of the straight line on the plot.
7. Save the EES file to Final_YourFirstName_YourLastName.EES
8. Submit the EES file on Canvas.

Equations Window

```

{S1=0
S2=0
S3=0
S4=0
S5=0

V1=0
V2=0
V3=0
V4=0
V5=0}

S=average(S1,S2,S3,S4,S5)
V=average(V1,V2,V3,V4,V5)

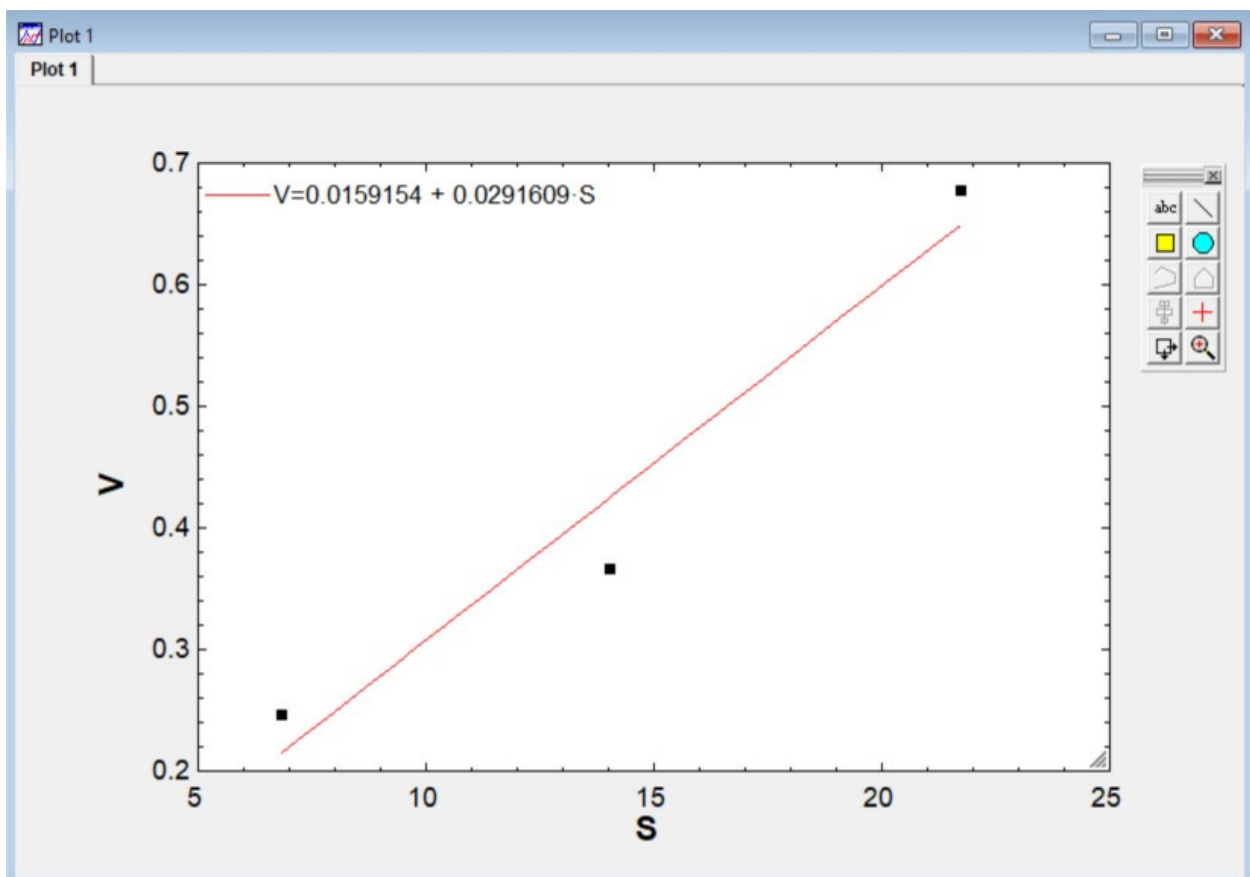
SL=abs(S1-S)^2+abs(S2-S)^2+abs(S3-S)^2+abs(S4-S)^2+abs(S5-S)^2
VL=abs(V1-V)^2+abs(V2-V)^2+abs(V3-V)^2+abs(V4-V)^2+abs(V5-V)^2

N=5
sigma_s = sqrt(SL/4)
sigma_v = sqrt(VL/4)

```

Parametric Table

Table 1	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	S1	S2	S3	S4	S5	V1	V2	V3	V4	V5	S	V	σ_v	σ_s
Run 1	6.7	6.4	7.1	6.7	7.3	0.23	0.27	0.25	0.25	0.23	6.84	0.246	0.01673	0.3578
Run 2	14.7	13.8	14.1	13.9	13.7	0.33	0.38	0.39	0.38	0.35	14.04	0.366	0.0251	0.3975
Run 3	21.5	22	22.1	21.9	21.1	0.65	0.65	0.72	0.69	0.68	21.72	0.678	0.0295	0.4147



ABOVE AVERAGE

Student name: Darius Jackson-Rubio

100

```
Equations Window

{S1=0
S2=0
S3=0
S4=0
S5=0

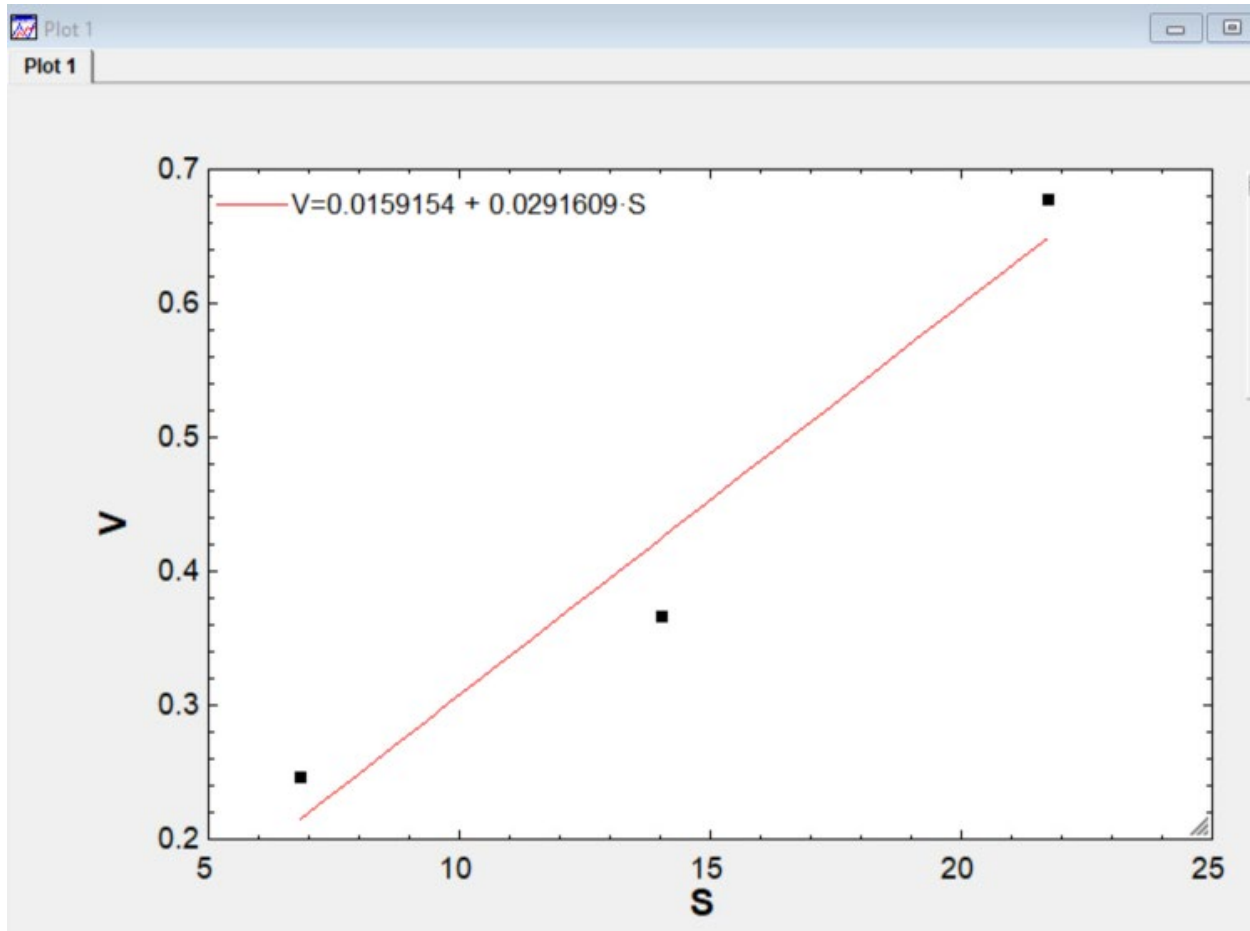
V1=0
V2=0
V3=0
V4=0
V5=0}

S=average(S1,S2,S3,S4,S5)
V=average(V1,V2,V3,V4,V5)

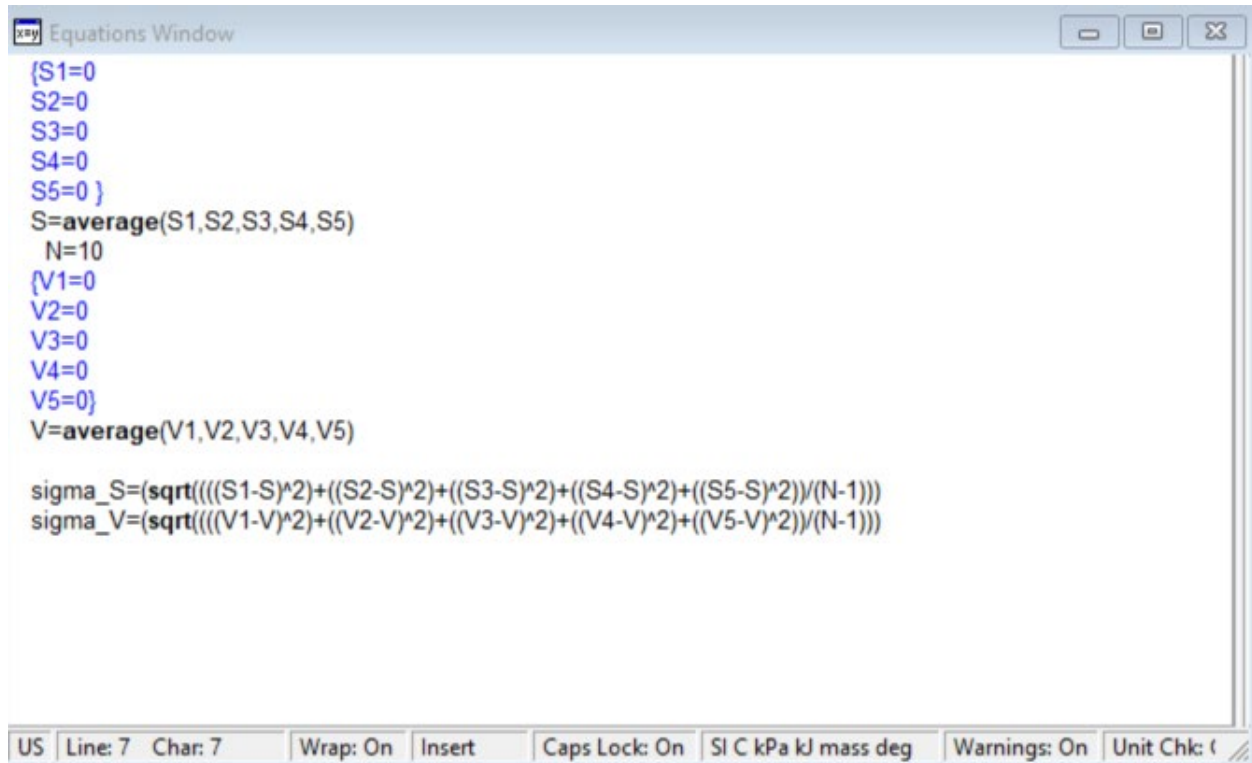
N=5

Sigma_S= sqrt(((S1-S)^2+(S2-S)^2+(S3-S)^2+(S4-S)^2+(S5-S)^2)/(N-1))
Sigma_V= sqrt(((V1-V)^2+(V2-V)^2+(V3-V)^2+(V4-V)^2+(V5-V)^2)/(N-1))
```

Parametric Table															
Table 2															
1.3	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	S1	S2	S3	S4	S5	V1	V2	V3	V4	V5	S	V	σ_S	σ_V	
Run 1	6.7	6.4	7.1	6.7	7.3	0.23	0.27	0.25	0.25	0.23	6.84	0.246	0.3578	0.01673	
Run 2	14.7	13.8	14.1	13.9	13.7	0.33	0.38	0.39	0.38	0.35	14.04	0.366	0.3975	0.0251	
Run 3	21.5	22	22.1	21.9	21.1	0.65	0.65	0.72	0.69	0.68	21.72	0.678	0.4147	0.0295	

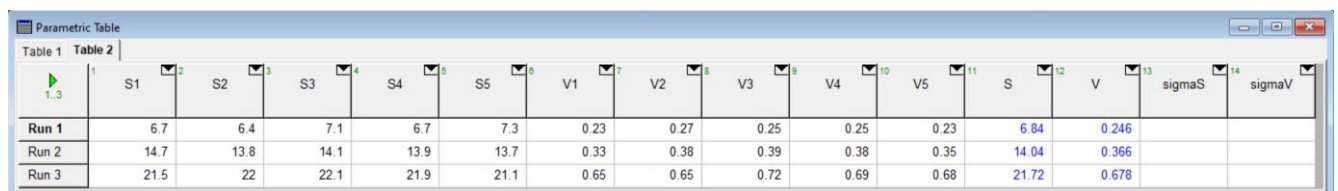


AVERAGE

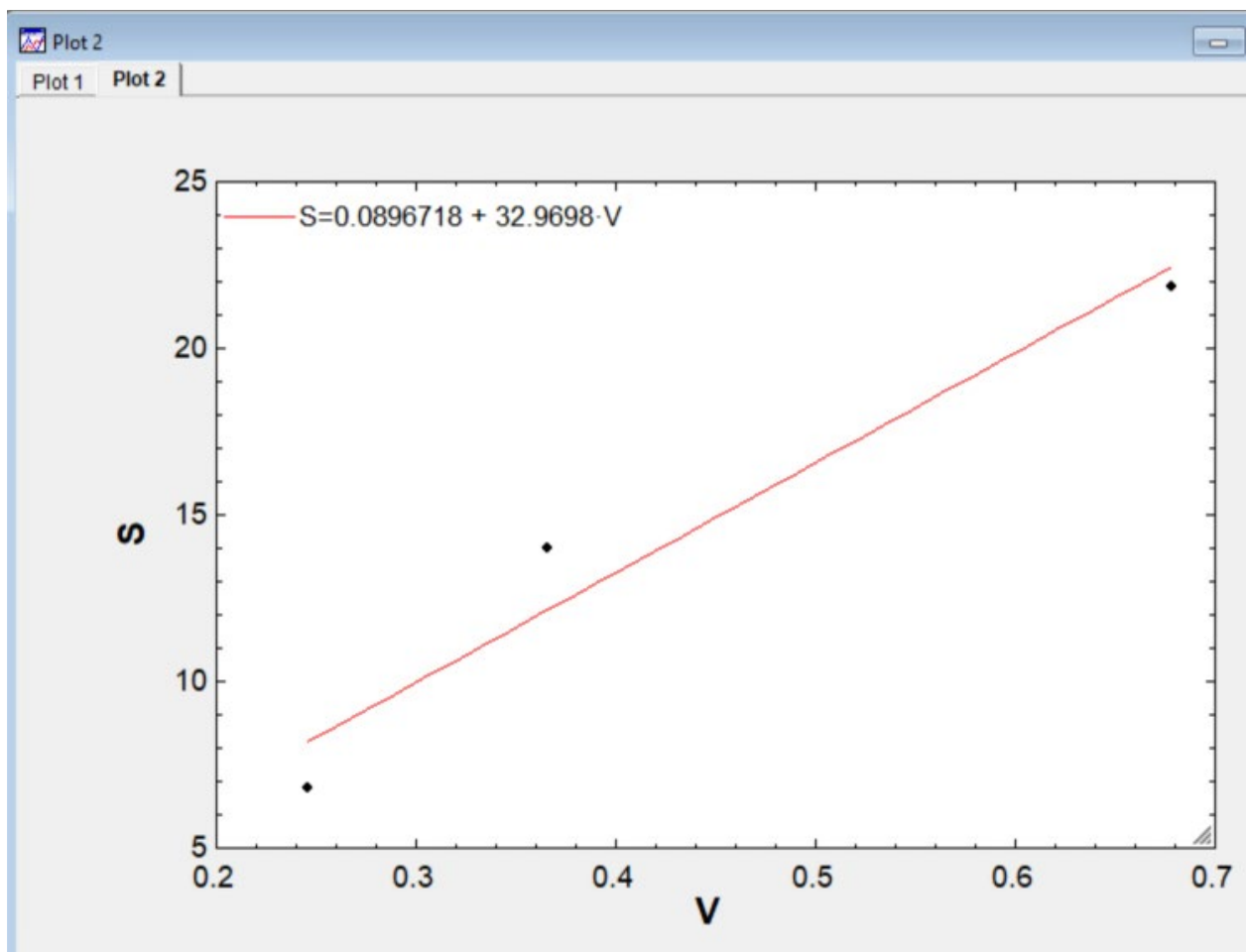
A screenshot of the 'Equations Window' in a software application. The window has a title bar with a small icon and standard window controls. The main area contains a list of equations and variables. The first five lines are initialization statements for S1 through S5, followed by a closing brace. Then, S is defined as the average of S1 through S5, and N is set to 10. Next, V1 through V5 are initialized, followed by a closing brace. Then, V is defined as the average of V1 through V5. Finally, two sigma variables are defined using the sqrt function and the sum of squared deviations from the mean, divided by (N-1). The status bar at the bottom shows 'US', 'Line: 7 Char: 7', 'Wrap: On', 'Insert', 'Caps Lock: On', 'SI C kPa kJ mass deg', 'Warnings: On', and 'Unit Chk: ('.

```
{S1=0
S2=0
S3=0
S4=0
S5=0 }
S=average(S1,S2,S3,S4,S5)
N=10
{V1=0
V2=0
V3=0
V4=0
V5=0}
V=average(V1,V2,V3,V4,V5)

sigma_S=(sqrt((((S1-S)^2)+((S2-S)^2)+((S3-S)^2)+((S4-S)^2)+((S5-S)^2))/(N-1)))
sigma_V=(sqrt((((V1-V)^2)+((V2-V)^2)+((V3-V)^2)+((V4-V)^2)+((V5-V)^2))/(N-1)))
```

A screenshot of the 'Parametric Table' window. It shows a table with 14 columns and 4 rows. The columns are labeled S1, S2, S3, S4, S5, V1, V2, V3, V4, V5, S, V, sigmaS, and sigmaV. The first row is a header row. The subsequent three rows are labeled 'Run 1', 'Run 2', and 'Run 3'. The values in the table are numerical, with some cells containing blue text. The status bar at the bottom shows 'US', 'Line: 7 Char: 7', 'Wrap: On', 'Insert', 'Caps Lock: On', 'SI C kPa kJ mass deg', 'Warnings: On', and 'Unit Chk: ('.

	S1	S2	S3	S4	S5	V1	V2	V3	V4	V5	S	V	sigmaS	sigmaV
Run 1	6.7	6.4	7.1	6.7	7.3	0.23	0.27	0.25	0.25	0.23	6.84	0.246		
Run 2	14.7	13.8	14.1	13.9	13.7	0.33	0.38	0.39	0.38	0.35	14.04	0.366		
Run 3	21.5	22	22.1	21.9	21.1	0.65	0.65	0.72	0.69	0.68	21.72	0.678		



BELOW AVERAGE

Student name: Rickya Jones

65

n1=7

n2=14

n3=22

S1=6.7*in, 14.7*in, 21.5*in

S2=6.48*in, 13.8*in, 22.0*in

S3=7.1*in, 14.1*in, 22.1*in

S4=6.7*in, 13.9*in, 21.9*in

S5=7.3*in, 13.7*in, 21.1*in

V1=0.23*V

V2=0.27*V

V3=0.25*V

V4=0.25*V

V5=0.23*V

V1=0.33*V

V2=0.388*V

V3=0.39*V

V4=0.38*V

V5=0.35*V

V1=0.65*V

V2=0.65*V

V3=0.72*V

V4=0.69*V

V5=0.68*V

S= (S1+S2+S3+S4+S5)/2

V= (V1+V2+V3+V4+V5)/2

Table 1										
	1	2	3	4	5	6	7	8	9	10
	S1	S2	S3	S4	S5	V1	V2	V3	V4	V5
Run 1	6.7	6.4	7.1	6.7	7.3	0.23	0.27	0.25	0.25	0.23
Run 2	14.7	13.8	14.1	13.9	13.7	0.33	0.38	0.39	0.38	0.35
Run 3	21.5	22	22.1	21.9	21.1	0.65	0.65	0.72	0.69	0.68

**MEASUREMENT AND INSTRUMENTATION LABORATORY
FALL 2021**

QUIZ 1

TOPICS COVERED IN QUIZ 1

Quiz 1 covered the following topics:

- Using Excel to do statistical analysis, including
1. Mean
 2. Mean deviation
 3. Standard deviation

**SAMPLE QUIZ 1 QUESTIONS, SOLUTION,
AND GRADING SCHEME FOR QUIZ 1**

1. Please calculate the Mean, Mean deviation, Standard Deviation for the Bolt 1, Bolt 2, Bolt 3 measurements given in the table below using the procedure introduced in the class. (Except Sum function, please do not use other embedded function in Excel)
2. After completing the calculations, please upload the Excel file to Canvas.

Unit:
inch

Bolt 1	Bolt 2	Bolt 3
0.9272	0.8273	0.9237
0.9261	0.8241	0.8231
0.9264	0.9252	0.9243
0.8330	0.9273	0.9495
0.9274	0.9265	0.9312
0.9293	0.9264	0.9266
0.9262	0.9320	0.9230
0.9273	0.9257	0.9258
0.9282	0.9254	0.9034
0.9272	0.9273	0.9237
0.8330	0.9273	0.9495
0.9274	0.9265	0.9312
0.9293	0.9264	0.9266
0.9262	0.9320	0.9230
0.9273	0.9257	0.9258
0.9282	0.9254	0.8034
0.9272	0.9273	0.9237
0.7261	0.8241	0.8231
0.9264	0.9252	0.9243
0.9290	0.9252	0.9237
0.9265	0.9492	0.9268
0.9330	0.9273	0.9495
0.9274	0.9265	0.9312
0.9293	0.9264	1.2266
0.9262	0.9320	0.9230
0.9273	0.9257	0.9258
0.9282	0.9254	0.9034
0.9272	0.9273	0.9237
0.9261	0.8241	0.8231
0.9264	0.9252	0.9243

	Unit: inch											
	Bolt 1	d	d2		Bolt 2	d	d2		Bolt 3	d	d2	
	0.9272	0.0127	0.00016044444444443		0.8273	0.0867	0.007524984177777790		0.9237	0.0015	0.000002250000000000	
	0.9261	0.0116	0.0001337877777777777		0.8241	0.0899	0.008090402844444460		0.8231	0.0991	0.009820809999999990	
	0.9264	0.0119	0.0001408177777777776		0.9252	0.0112	0.0001243968444444442		0.9243	0.0021	0.000004410000000000	
	0.8330	0.0815	0.006647684444444460		0.9273	0.0133	0.0001756508444444442		0.9495	0.0273	0.0007452899999999999	
	0.9274	0.0129	0.0001655511111111109		0.9265	0.0125	0.0001550855111111108		0.9312	0.0090	0.000081000000000000	
	0.9293	0.0148	0.0002180544444444442		0.9264	0.0124	0.0001526048444444442		0.9266	0.0044	0.000019360000000000	
	0.9262	0.0117	0.0001361111111111110		0.9320	0.0180	0.0003223221777777775		0.9230	0.0008	0.000000640000000000	
	0.9273	0.0128	0.0001629877777777776		0.9257	0.0117	0.0001358001777777774		0.9258	0.0036	0.000012960000000000	
	0.9282	0.0137	0.0001867777777777776		0.9254	0.0114	0.0001288981777777775		0.9034	0.0188	0.0003534400000000001	
	0.9272	0.0127	0.000160444444444443		0.9273	0.0133	0.0001756508444444442		0.9237	0.0015	0.000002250000000000	
	0.8330	0.0815	0.006647684444444460		0.9273	0.0133	0.0001756508444444442		0.9495	0.0273	0.0007452899999999999	
	0.9274	0.0129	0.0001655511111111109		0.9265	0.0125	0.0001550855111111108		0.9312	0.0090	0.000081000000000000	
	0.9293	0.0148	0.0002180544444444442		0.9264	0.0124	0.0001526048444444442		0.9266	0.0044	0.000019360000000000	
	0.9262	0.0117	0.0001361111111111110		0.9320	0.0180	0.0003223221777777775		0.9230	0.0008	0.000000640000000000	
	0.9273	0.0128	0.0001629877777777776		0.9257	0.0117	0.0001358001777777774		0.9258	0.0036	0.000012960000000000	
	0.9282	0.0137	0.0001867777777777776		0.9254	0.0114	0.0001288981777777775		0.8034	0.1188	0.014113440000000000	
	0.9272	0.0127	0.000160444444444443		0.9273	0.0133	0.0001756508444444442		0.9237	0.0015	0.000002250000000000	
	0.7261	0.1884	0.035507121111111200		0.8241	0.0899	0.008090402844444460		0.8231	0.0991	0.009820809999999990	
	0.9264	0.0119	0.0001408177777777776		0.9252	0.0112	0.0001243968444444442		0.9243	0.0021	0.000004410000000000	
	0.9290	0.0145	0.0002092844444444443		0.9252	0.0112	0.0001243968444444442		0.9237	0.0015	0.000002250000000000	
	0.9265	0.0120	0.0001432011111111109		0.9492	0.0352	0.0012357568444444440		0.9268	0.0046	0.0000211599999999999	
	0.9330	0.0185	0.0003410177777777776		0.9273	0.0133	0.0001756508444444442		0.9495	0.0273	0.0007452899999999999	
	0.9274	0.0129	0.0001655511111111109		0.9265	0.0125	0.0001550855111111108		0.9312	0.0090	0.000081000000000000	
	0.9293	0.0148	0.0002180544444444442		0.9264	0.0124	0.0001526048444444442		1.2266	0.3044	0.0926593599999999900	
	0.9262	0.0117	0.0001361111111111110		0.9320	0.0180	0.0003223221777777775		0.9230	0.0008	0.000000640000000000	
	0.9273	0.0128	0.0001629877777777776		0.9257	0.0117	0.0001358001777777774		0.9258	0.0036	0.000012960000000000	
	0.9282	0.0137	0.0001867777777777776		0.9254	0.0114	0.0001288981777777775		0.9034	0.0188	0.0003534400000000001	
	0.9272	0.0127	0.000160444444444443		0.9273	0.0133	0.0001756508444444442		0.9237	0.0015	0.000002250000000000	
	0.9261	0.0116	0.0001337877777777777		0.8241	0.0899	0.008090402844444460		0.8231	0.0991	0.009820809999999990	
	0.9264	0.0119	0.0001408177777777776		0.9252	0.0112	0.0001243968444444442		0.9243	0.0021	0.000004410000000000	
Sum	27.4360	0.7030	0.0534		27.4214	0.7132	0.0373		27.6660	0.9074	0.1395	
N	30	30	30	0	30	30	30	0	30	30	30	
Mean	0.914533	0.023433	0.001781208		0.914047	0.023772	0.001242252		0.9222	0.030247	0.004651538	
STD			0.042204363				0.035245602				0.068202185	

ABOVE AVERAGE

1. Please calculate the **Mean, Mean deviation, Standard Deviation** for the Bolt 1, Bolt 2, Bolt 3 measurements given in the table below using the procedure introduced in the class. (Except Sum function, please do not use other embeded function in Excel)

2. After completing the calculations, please upload the Excel file to Canvas.

Unit: inch

Bolt 1	d	d ^2	Bolt 2	d	d ^2	Bolt 3	d	d ^2
0.9272	0.0127	0.000160444444444443	0.8273	0.0867	0.00752498417777779	0.9237	0.0015	0.000002250000000000
0.9261	0.0116	0.000133787777777777	0.8241	0.0899	0.00809040284444446	0.8231	0.0991	0.009820809999999990
0.9264	0.0119	0.000140817777777776	0.9252	0.0112	0.000124396844444444	0.9243	0.0021	0.000004410000000000
0.8330	0.0815	0.006647684444444470	0.9273	0.0133	0.000175650844444444	0.9495	0.0273	0.000745290000000000
0.9274	0.0129	0.0001655511111111109	0.9265	0.0125	0.000155085511111111	0.9312	0.0090	0.000081000000000000
0.9293	0.0148	0.000218054444444442	0.9264	0.0124	0.000152604844444444	0.9266	0.0044	0.000019360000000000
0.9262	0.0117	0.0001361111111111110	0.9320	0.0180	0.000322322177777778	0.9230	0.0008	0.000000640000000000
0.9273	0.0128	0.000162987777777776	0.9257	0.0117	0.000135800177777777	0.9258	0.0036	0.000012960000000000
0.9282	0.0137	0.000186777777777776	0.9254	0.0114	0.000128898177777778	0.9034	0.0188	0.000353440000000001
0.9272	0.0127	0.000160444444444443	0.9273	0.0133	0.000175650844444444	0.9237	0.0015	0.000002250000000000
0.8330	0.0815	0.006647684444444470	0.9273	0.0133	0.000175650844444444	0.9495	0.0273	0.000745290000000000
0.9274	0.0129	0.0001655511111111109	0.9265	0.0125	0.000155085511111111	0.9312	0.0090	0.000081000000000000
0.9293	0.0148	0.000218054444444442	0.9264	0.0124	0.000152604844444444	0.9266	0.0044	0.000019360000000000
0.9262	0.0117	0.0001361111111111110	0.9320	0.0180	0.000322322177777778	0.9230	0.0008	0.000000640000000000
0.9273	0.0128	0.000162987777777776	0.9257	0.0117	0.000135800177777777	0.9258	0.0036	0.000012960000000000
0.9282	0.0137	0.000186777777777776	0.9254	0.0114	0.000128898177777778	0.8034	0.1188	0.014113440000000000
0.9272	0.0127	0.000160444444444443	0.9273	0.0133	0.000175650844444444	0.9237	0.0015	0.000002250000000000
0.7261	0.1884	0.0355071211111111200	0.8241	0.0899	0.00809040284444446	0.8231	0.0991	0.009820809999999990
0.9264	0.0119	0.000140817777777776	0.9252	0.0112	0.000124396844444444	0.9243	0.0021	0.000004410000000000
0.9290	0.0145	0.000209284444444443	0.9252	0.0112	0.000124396844444444	0.9237	0.0015	0.000002250000000000
0.9265	0.0120	0.0001432011111111109	0.9492	0.0352	0.001235756844444444	0.9268	0.0046	0.000021159999999999
0.9330	0.0185	0.000341017777777777	0.9273	0.0133	0.000175650844444444	0.9495	0.0273	0.000745290000000000
0.9274	0.0129	0.0001655511111111109	0.9265	0.0125	0.000155085511111111	0.9312	0.0090	0.000081000000000000
0.9293	0.0148	0.000218054444444442	0.9264	0.0124	0.000152604844444444	1.2266	0.3044	0.092659359999999900
0.9262	0.0117	0.0001361111111111110	0.9320	0.0180	0.000322322177777778	0.9230	0.0008	0.000000640000000000
0.9273	0.0128	0.000162987777777776	0.9257	0.0117	0.000135800177777777	0.9258	0.0036	0.000012960000000000
0.9282	0.0137	0.000186777777777776	0.9254	0.0114	0.000128898177777778	0.9034	0.0188	0.000353440000000001
0.9272	0.0127	0.000160444444444443	0.9273	0.0133	0.000175650844444444	0.9237	0.0015	0.000002250000000000
0.9261	0.0116	0.000133787777777777	0.8241	0.0899	0.00809040284444446	0.8231	0.0991	0.009820809999999990
0.9264	0.0119	0.000140817777777776	0.9252	0.0112	0.000124396844444444	0.9243	0.0021	0.000004410000000000
27.4360	0.7030	0.0534	27.4214	0.7132	0.0373	27.6660	0.9074	0.1395
30	30	30	30	30	30	30	30	30
Mean	0.9145	0.0234	0.0018	0.9140	0.0238	0.0012	0.9222	0.0302
Mean Deviation								
STD		0.042204363			0.035245602			0.068202185

AVERAGE

1. Please calculate the **Mean, Mean deviation, Standard Deviation** for the Bolt 1, Bolt 2, Bolt 3 measurements given in the table below using the procedure introduced in the class. (Except Sum function, please do not use other embeded function in Excel)

2. After completing the calculations, please upload the Excel file to Canvas.

Unit: inch

	Bolt 1	d	d^2	Bolt 2	d	d^2	Bolt 3	d	d^2
	0.9272	0.0004	1.78272E-07	0.8273	0.0029	8.36E-06	0.9237	0.0000	2.5E-09
	0.9261	0.0004	1.48653E-07	0.8241	0.0030	8.99E-06	0.8231	0.0033	1.09E-05
	0.9264	0.0004	1.56464E-07	0.9252	0.0004	1.38E-07	0.9243	0.0001	4.9E-09
	0.8330	0.0027	7.38632E-06	0.9273	0.0004	1.95E-07	0.9495	0.0009	8.28E-07
	0.9274	0.0004	1.83946E-07	0.9265	0.0004	1.72E-07	0.9312	0.0003	9E-08
	0.9293	0.0005	2.42283E-07	0.9264	0.0004	1.7E-07	0.9266	0.0001	2.15E-08
	0.9262	0.0004	1.51235E-07	0.9320	0.0006	3.58E-07	0.9230	0.0000	7.11E-10
	0.9273	0.0004	1.81098E-07	0.9257	0.0004	1.51E-07	0.9258	0.0001	1.44E-08
	0.9282	0.0005	2.07531E-07	0.9254	0.0004	1.43E-07	0.9034	0.0006	3.93E-07
	0.9272	0.0004	1.78272E-07	0.9273	0.0004	1.95E-07	0.9237	0.0000	2.5E-09
	0.8330	0.0027	7.38632E-06	0.9273	0.0004	1.95E-07	0.9495	0.0009	8.28E-07
	0.9274	0.0004	1.83946E-07	0.9265	0.0004	1.72E-07	0.9312	0.0003	9E-08
	0.9293	0.0005	2.42283E-07	0.9264	0.0004	1.7E-07	0.9266	0.0001	2.15E-08
	0.9262	0.0004	1.51235E-07	0.9320	0.0006	3.58E-07	0.9230	0.0000	7.11E-10
	0.9273	0.0004	1.81098E-07	0.9257	0.0004	1.51E-07	0.9258	0.0001	1.44E-08
	0.9282	0.0005	2.07531E-07	0.9254	0.0004	1.43E-07	0.8034	0.0040	1.57E-05
	0.9272	0.0004	1.78272E-07	0.9273	0.0004	1.95E-07	0.9237	0.0000	2.5E-09
	0.7261	0.0063	3.94524E-05	0.8241	0.0030	8.99E-06	0.8231	0.0033	1.09E-05
	0.9264	0.0004	1.56464E-07	0.9252	0.0004	1.38E-07	0.9243	0.0001	4.9E-09
	0.9290	0.0005	2.32538E-07	0.9252	0.0004	1.38E-07	0.9237	0.0000	2.5E-09
	0.9265	0.0004	1.59112E-07	0.9492	0.0012	1.37E-06	0.9268	0.0002	2.35E-08
	0.9330	0.0006	3.78909E-07	0.9273	0.0004	1.95E-07	0.9495	0.0009	8.28E-07
	0.9274	0.0004	1.83946E-07	0.9265	0.0004	1.72E-07	0.9312	0.0003	9E-08
	0.9293	0.0005	2.42283E-07	0.9264	0.0004	1.7E-07	1.2266	0.0101	0.000103
	0.9262	0.0004	1.51235E-07	0.9320	0.0006	3.58E-07	0.9230	0.0000	7.11E-10
	0.9273	0.0004	1.81098E-07	0.9257	0.0004	1.51E-07	0.9258	0.0001	1.44E-08
	0.9282	0.0005	2.07531E-07	0.9254	0.0004	1.43E-07	0.9034	0.0006	3.93E-07
	0.9272	0.0004	1.78272E-07	0.9273	0.0004	1.95E-07	0.9237	0.0000	2.5E-09
	0.9261	0.0004	1.48653E-07	0.8241	0.0030	8.99E-06	0.8231	0.0033	1.09E-05
	0.9264	0.0004	1.56464E-07	0.9252	0.0004	1.38E-07	0.9243	0.0001	4.9E-09
N	30	30	30	30	30	30	30	30	30
Sum	27.4360	0.0234	0.0001	27.4214	0.0238	0.0000	27.6660	0.0302	0.0002
Mean	0.914533	0.000781	1.97912E-06	0.914047	0.000792	1.38E-06	0.9222	0.001008	5.17E-06
Mean Deviation		0.000781	6.10135E-07		0.000792	6.28E-07		0.001008	1.02E-06
Standard Deviation			0.00078111			0.000792			0.001008

BELOW AVERAGE



1. Please calculate the **Mean, Mean deviation, Standard Deviation** for the Bolt 1, Bolt 2, Bolt 3 measurements given in the table below using the procedure introduced in the class. (Except Sum function, please do not use other embeded function in Excel)

Unit: inch							
Bolt 1	Bolt 2	Bolt 3	Column1	bolt 1	bolt2	bolt 3	bolt 4
0.9272	-0.7270	0.9237	mean	0.9592	0.85583	0.9559	X
0.9261	0.8241	0.8231	mean deviatric	0.9580	0.7899	0.9202	
0.9264	0.9252	0.9243	standard deva	0.6680	0.548	0.6987	
0.8330	0.9273	0.9495					
0.9274	0.9265	0.9312					
0.9293	0.9264	0.9266					
0.9262	0.9320	0.9230					
0.9273	0.9257	0.9258					
0.9282	0.9254	0.9034					
0.9272	0.9273	0.9237					
0.8330	0.9273	0.9495					
0.9274	0.9265	0.9312					
0.9293	0.9264	0.9266					
0.9262	0.9320	0.9230					
0.9273	0.9257	0.9258					
0.9282	0.9254	0.8034					
0.9272	0.9273	0.9237					
0.7261	0.8241	0.8231					
0.9264	0.9252	0.9243					
0.9290	0.9252	0.9237					
0.9265	0.9492	0.9268					
0.9330	0.9273	0.9495					
0.9274	0.9265	0.9312					
0.9293	0.9264	1.2266					
0.9262	0.9320	0.9230					
0.9273	0.9257	0.9258					
0.9282	0.9254	0.9034					
0.9272	0.9273	0.9237					
0.9261	0.8241	0.8231					
0.9264	0.9252	0.9243					

MEASUREMENT AND INSTRUMENTATION LABORATORY FALL 2021

QUIZ 2

TOPICS COVERED IN QUIZ 2

Quiz 2 covered the following topics:

Using Engineering Equation Solver (EES) to do statistical analysis, including

1. Set up parametric table to solve equations in batch
2. Plot dependent variable vs independent variable
3. Perform linear regression and identify the statistics of the fitting and slope

**SAMPLE QUIZ 2 QUESTIONS, SOLUTION,
AND GRADING SCHEME FOR QUIZ 2**

MCEG 3101 Measurement and Instrumentation Laboratory Quiz 2

This is a close book, close notes exam
Duration: 40 minutes

Theory:

Sonar is a technique that uses sound propagation to navigate, communicate with or detect objects on or under the surface of the water.

Active sonar sensors are fitted with an emitter that generates ultrasonic waves and a receiver that captures them after hitting a target. The voltage signal generated from the sonar sensor is proportional to the distance between the target and the sonar sensor. As the target moving away from the sonar sensor, the measured voltage increases.

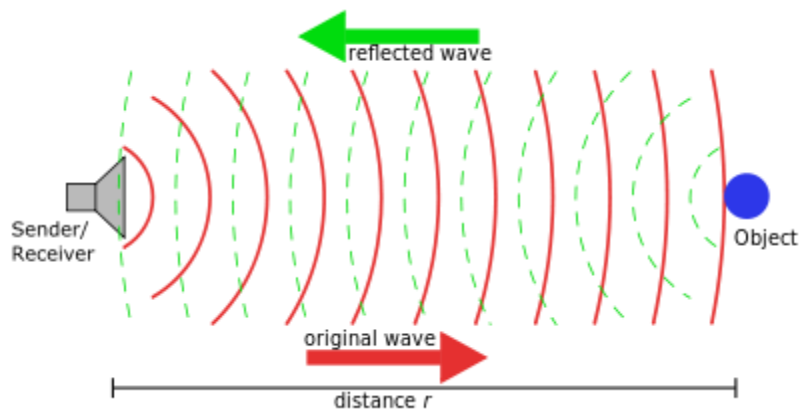


Figure 1 principle of an active sonar (from <https://en.wikipedia.org/wiki/Sonar>).

A sturdy piece of cardboard can be used as a target to calibrate the sonar sensor. Begin with the target close to the sonar sensor and slowly move it further away from the sensor. When the target is set at one position, measure the actual distance between the target and the sensor 5 times, and record the corresponding voltage from the sonar sensor. Repeat for different target positions and summarize in Table 1.

Table1 Collected data for sonar sensor calibration.

Actual distance between the target and the sensor T (in)	Sensor Measurement V (volts)
7	V1 = 0.25
14	V1 = 0.39
22	V1 = 0.71

Analysis and Results:

1. Create a parametric table in EES with the columns T, V
2. Plot V versus T. Set the vertical axis to V, and horizontal axis to T.
3. Use EES to fit the best straight line through the points.
4. Plot the equation of the straight line on the plot.
5. Save the EES file to Quiz2_YourFirstName_YourLastName.EES
6. Submit the EES file on eCourses.

Equations Window

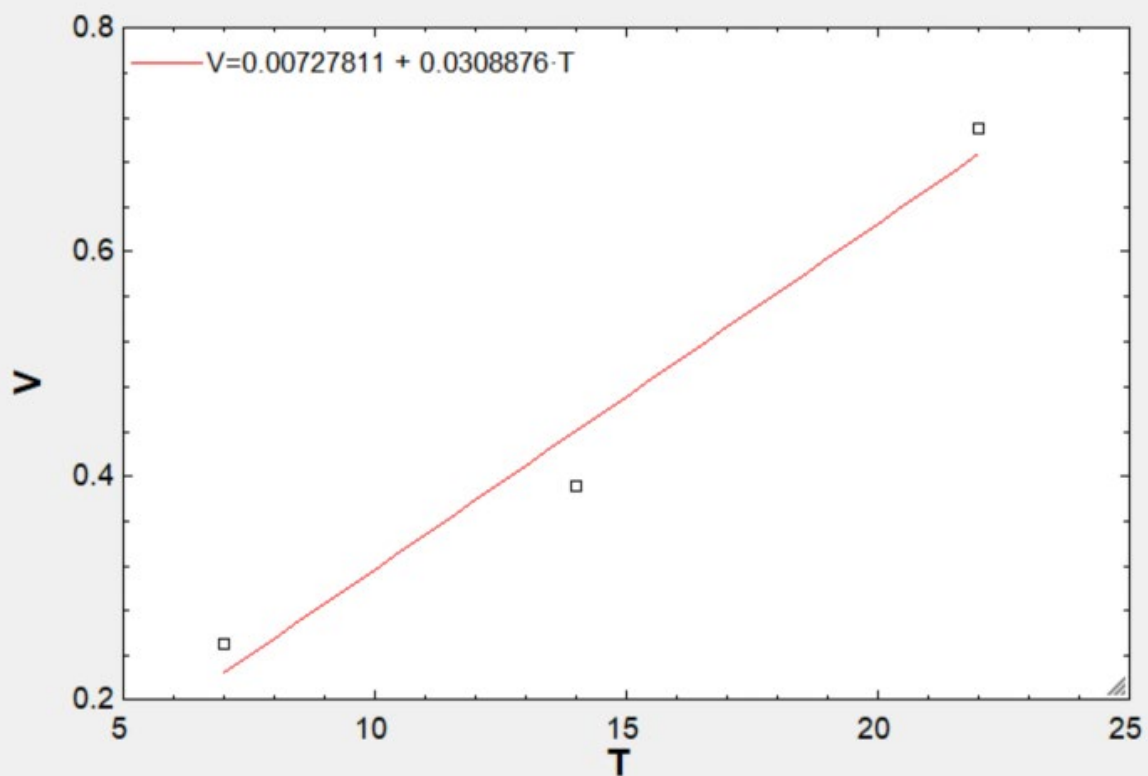
T=0
V=0

Parametric Table		
Table 1		
1..3	T	V
Run 1	7	0.25
Run 2	14	0.39
Run 3	22	0.71

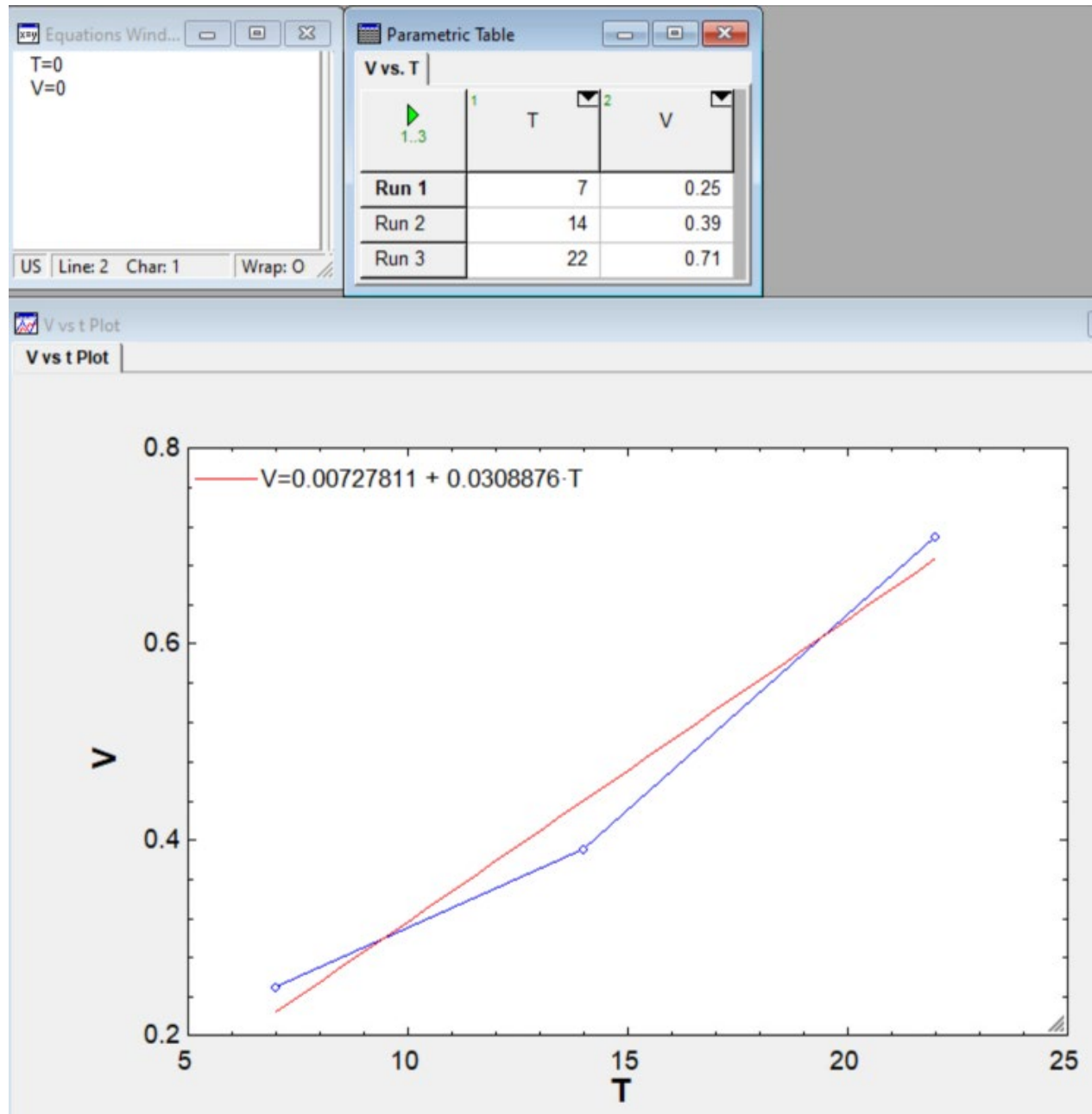
US Line: 2 Char: 4 Wrap: On Insert Caps Lock: Off SI C kPa kJ mass deg Warnings: On Unit Chk: On

Plot 1

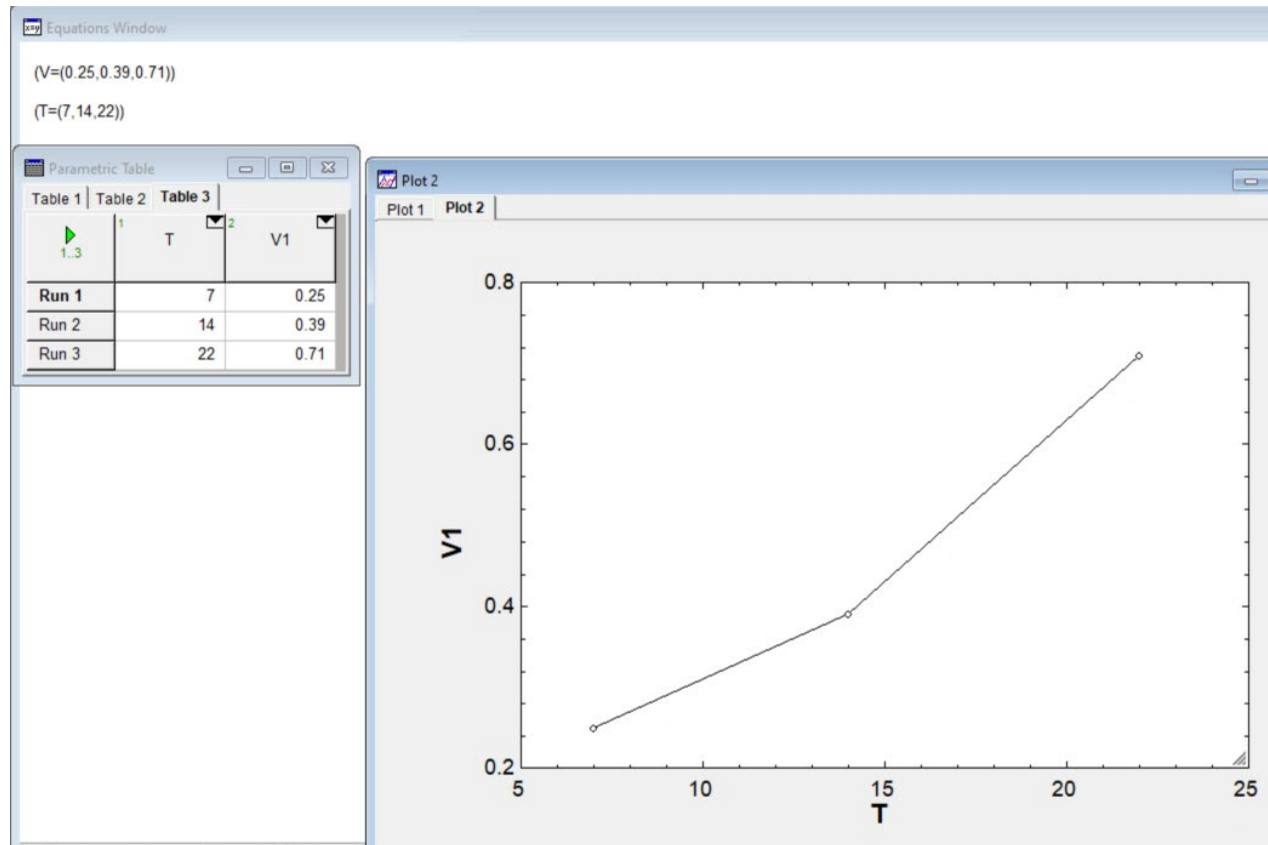
Plot 1



ABOVE AVERAGE



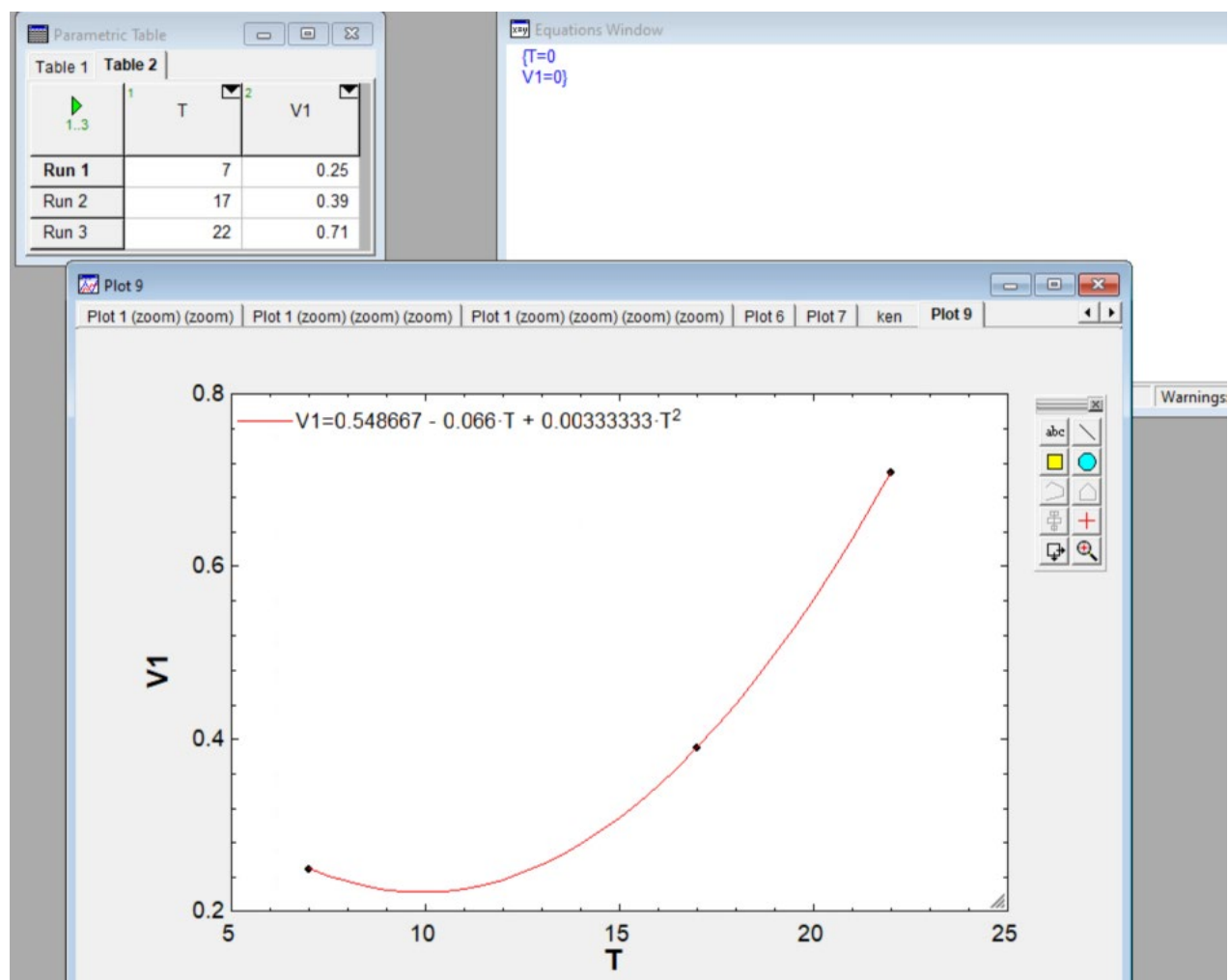
AVERAGE



Missing curve fit and wrong equations.

BELOW AVERAGE

65



**MEASUREMENT AND INSTRUMENTATION LABORATORY
FALL 2021**

LABORATORY REPORT # 1

TOPICS COVERED IN LABORATORY EXPERIMENT #1

**EXPERIMENT #1
PRECISE MEASUREMENT USING MICROMETERS &
INTRODUCTION TO STATISTICAL ANALYSIS OF
EXPERIMENTAL DATA**

The objectives of the experiment are to:

- 1. Learn the use of micrometers for precise measurements.**
- 2. Introduce the use of statistical analysis of experimental data using the mean, deviation, the mean deviation and the standard deviation.**
- 3. Plot histograms for a set of experimental data represented by the mean and the standard deviation in the form of $(x_m \pm \sigma)$**

**MEASUREMENT AND INSTRUMENTATION LABORATORY
FALL 2021**

LABORATORY HANDOUT FOR EXPERIMENT 1

**PRECISE MEASUREMENT USING MICROMETERS &
INTRODUCTION TO STATISTICAL ANALYSIS OF
EXPERIMENTAL DATA**

PRECISE MEASUREMENT USING MICROMETERS & INTRODUCTION TO STATISTICAL ANALYSIS OF EXPERIMENTAL DATA

Objectives:

The objectives of the experiment are to:

1. Learn the use of micrometers for precise measurements.
2. Introduce the use of statistical analysis of experimental data using the mean, deviation, the mean deviation and the standard deviation.
3. Plot histograms for a set of experimental data represented by the mean and the standard deviation in the form of $(x_m \pm \sigma)$

Theory

Statistical Analysis of Experimental Data

In many situations, it is necessary to conduct several sets of experiments to ensure that the statistical accuracy of the results can be determined. A number of statistical parameters are needed to determine the statistical accuracy of the experimental results. The statistical parameters to be discussed in this section include the mean, the deviation of each data from the mean, the average deviation, and the standard deviation or the root mean square deviation.

The Mean: The mean x_m , of a set of n data in which each data is represented by x_i ($i=1$ to n) is given by

$$x_m = \frac{1}{n} \sum_{i=1}^n x_i \quad (1)$$

The Deviation: The deviation d_i of a set of n data in which each data is represented by x_i ($i=1$ to n) is given by

$$d_i = x_i - x_m \quad (2)$$

Note that the average of the deviations of all the data is zero since the sum of the deviation is zero.

The Mean Deviation: The average of the absolute values of the deviations is however not zero, and is given by

$$\bar{d}_i = \frac{1}{n} \sum |x_i - x_m| \quad (3)$$

The Standard Deviation: The standard deviation is also known as the root mean square deviation. It is one of the most important statistical parameters that is used to ascertain the accuracy as well as the confidence one will have in the value of the measured data. The standard deviation for a very large set of data is given by

$$\sigma = \left[\frac{1}{n} \sum_{i=1}^n (x_i - x_m)^2 \right]^{1/2} \quad (4)$$

When the number of data is not large (greater than 20 for example), the sample standard deviation is given by

$$\sigma = \left[\frac{\sum (x_i - x_m)^2}{n - 1} \right]^{1/2} \quad (5)$$

The Covariance: $COV = \text{Standard Deviation} / \text{Mean}$

Apparatus

The Micrometer

Parts and How to Use a Micrometer [1]

The main parts of the micrometer shown in Figure 1 are the anvil, the spindle, the sleeve the thimble and the ratchet.

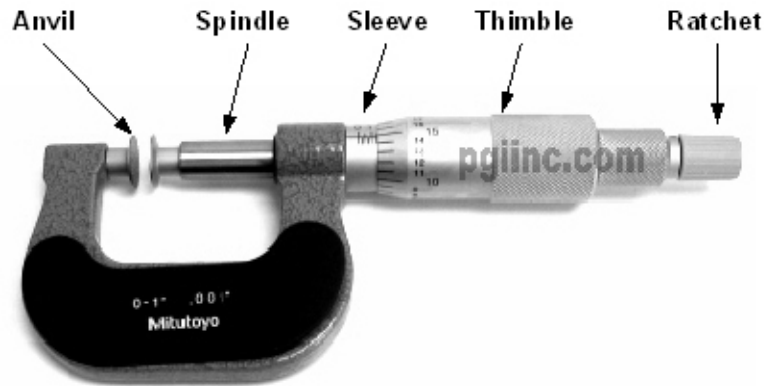


Figure 1 Parts of a Micrometer

Sleeve: The Micrometer sleeve is divided into 10 equal parts, each of these parts is equal to $.100''$ (1 tenth of an inch). Each of these 10 parts is divided into 4 equal parts. Each of these 4 subdivisions is equal to $.025''$ or one 40th of an inch. More simply, the line on the sleeve marked "1" represents $.100''$, the line marked "2" represents $.200''$ and so forth.

Thimble: The thimble is divided into twenty-five equal parts, each of these parts is equal to $.001''$ and, one complete rotation of the thimble coincides with the smallest division ($.025''$) on the sleeve.

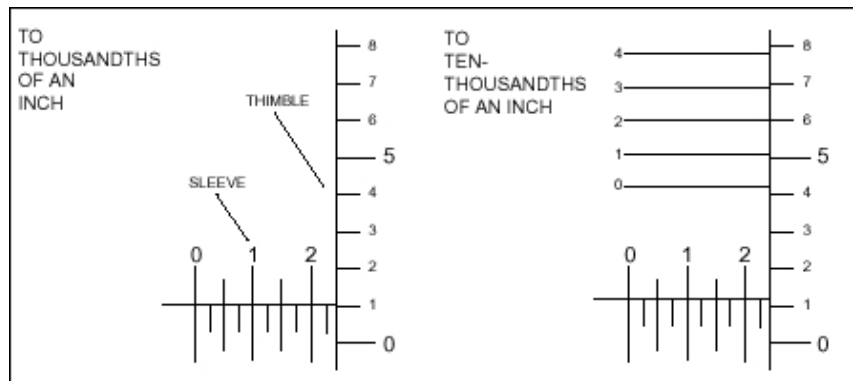


Figure 2 Example Measurements

Taking a Reading on a $.001''$ Micrometer

To read either a $.001''$ or $.0001''$ micrometer, you place the material to be measured between the anvil and spindle, and then turn the ratchet until the spindle closes down and stops moving. Then you read the markings on the sleeve and thimble. In the case of a $.0001''$ micrometer you would then read the markings on the vernier scale to get the $.0001''$ measurement

In our example below, as we take our measurement, we fill in a box for each reading. We suggest you try this method while you are learning to measure with outside micrometers. Soon enough, you will become very fast reading these micrometers

1. Read the sleeve:

a. In Figure 2 above, when tightening down the thimble on our material, it stopped at a point to the right of "2" on the sleeve, this indicates .200". We wrote this in row (1) in the table below.

b. There is one line visible between the graduation numbered "2" on the sleeve and the edge of the thimble, this indicates .025". We wrote this in row (2) in the table below.

1. Read the thimble: The graduation numbered "1" on the thimble coincides with the center line of the sleeve. This indicates .001". We wrote this in (3) in the table below.

2. Add it all up: Now just add all the numbers together to determine the thickness of your material.

Table 1 Adding Up

(1) Reading on the Sleeve	.200"
(2) No. of lines between "2" and the edge of the thimble	.025"
(3) Thimble line corresponding to the center line of the sleeve	.001"
TOTAL READING	.226"

Procedure

1. Study the information from the information on “**Parts and How to Use a Micrometer**” provided above and from several information available on the web.
2. Identify the five steel bolts numbered 1, 2, 3, 4, and 5 on the bolt-head.
3. Also identify the unthreaded neck portion between the threaded section and the bolt-head.
4. Measure, to 0.001 inch, the diameter at the neck section of the bolt #1 and record your measurement in the personal table provided to you, ensuring that other members in your group do not see your measurement in order to eliminate bias in the measurements.
5. Repeat step 4 for bolts 2, 3, 4, and 5.
6. Steps 1 through 5 should be repeated by each member in the lab group.
7. When all members in the group complete the measurements, the group leader should collect the table from the members of the group and include the group number on the first page.
8. The group leader should submit the results to the course instructor.
9. The course instructor will collect the results from all of the groups.
10. The course instructor will redistribute a set of the results from a group to the group leader in another group.
11. The group leaders should record the data for the group given to the leader on the master table in the classroom before the end of the class.
12. Each student will make a photographic image of the master table containing the entire results or the course instructor will scan and post the master results on e-course for all students to access.

Table 2 Raw Experimental Data for Measurements of Diameter of Bolts Using Micrometer

#	Name of Student	Bolt #1	Bolt #2	Bolt #3	Bolt #4	Bolt #5
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						
26						
27						
28						
29						
30						

Analysis and Lab Report.

For this lab you can demonstrate your understanding of the statistical analysis discussed in the theory using Excel. However, you are not allowed to use the built-in functions to compute any of the statistical variables in the theory section.

1. For the set of data for bolt 1, compute the sum using the sum function of excel
2. Using the number of data in the set and the sum, compute the mean using equation 1.
3. In a column next to the data column for Bolt 1, compute the absolute value of the deviation of each data from the mean using equation 2 in the absolute value sense.
4. Compute the mean deviation for the measurements for Bolt 1 using equation 3.
5. In a column next to the absolute deviation column, compute the squares of the deviations, i.e. $(x_i - x_m)^2$.
6. Compute the standard deviation using equation 4 or 5, whichever is applicable.
7. Repeat steps 1 through 6 for bolts 2, 3, 4, and 5.
8. Summarize your results for the five bolts in a table similar to the one below in excel.

Table 3 Summary of Computed Results

	Bolt 1	Bolt 2	Bolt 3	Bolt 4	Bolt 5
Mean, x_m					
Mean Deviation, $ d $					
Standard Deviation, σ					
The Covariance σ/Mean					

Table 4 Computed results for the five bolts

	X	$ d $	d^2
Bolt 1			
Bolt 2			
Bolt 3			
Bolt 4			
Bolt 5			
Sum			
N			
Mean			
STD			

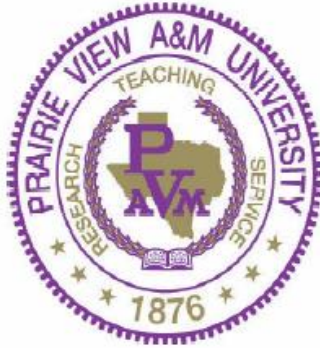
9. Using the computed means for each set of bolts in Table 3 repeat steps 2 to 4 to compute the mean, the standard deviation and the covariance for the five bolts. Put the results in Table 4.
10. Make a histogram plot of the mean (Y-axis) versus the Bolts (x-axis) and show error bars at one standard deviation. Make sure Y-axis starts at 0.
11. Make a histogram plot of the mean deviation (Y-axis) versus the Bolts (x-axis). Do not show error bar. Make sure Y-axis starts at 0.
12. Make a histogram plot of the Covariance (Y-axis) versus the Bolts (x-axis). Do not show error bar. Make sure Y-axis starts at 0.
13. Complete the lab report following the lab report template. Please pay particular attention to the last chapter of the report. Clearly indicate the significance of the mean, the standard deviation, and the covariance.

REFERENCES

- [1] Precision Graphic Instruments, Inc, www.pgiinc.com/howtoreoumi.html, 9/9/2007.

ABOVE AVERAGE

**MECHANICAL ENGINEERING DEPARTMENT
PRAIRIE VIEW A&M UNIVERSITY**



MCEG 3101 MEASUREMENT LABORATORY

Fall 2021 Section P01

LABORATORY REPORT ON

“Measurement Using Micrometers and Statistical Analysis of Data”

**Conducted on
September 7, 2021**

**Submitted by
Darius Jackson-Rubio**

**On
September 14, 2021**

To

**Dr. Mingli Han
*Measurement Laboratory Instructor***

**MECHANICAL ENGINEERING DEPARTMENT
MEASUREMENT LABORATORY GRADING SHEET
FALL 2021 SECTION P01**

Title of Experiment: _ Measurement Using Micrometers and Statistical Analysis of Data

Name: ___Darius Jackson-Rubio_____

Date Lab was Performed: ___9/7/2021_____

Report Due

Date:___9/14/2021_____

<i>Ability to Conduct Experiments</i>	MAX	Your Score	Comments
Ability to demonstrate general lab safety (by your conduct and observations).	3	2	
Ability to follow the procedure and properly rephrasing the procedure to reflect what you did during the experiment.	7	7	
Ability to demonstrate knowledge of how equipment function, their limitations, and the uncertainty associated with reading the instruments.	5	5	
Ability to collect and record the raw data using appropriate units of measurement and identify the dependent and independent variables in the experiment.	5	5	
Total for Ability to Conduct Experiments	20	20	
Percentage for this Performance Criteria			
<i>Ability to Analyze and Interpret experimental Data in a Formal Report</i>			
Report format (Ability to properly format and present a technical report)	13	9	
Provides appropriate abstracts for the experimental report	5	5	
Ability to analyze the data using appropriate software to generate the required parameters using consistent units	27	25	
Ability to present the data (raw /derived) in tabular and graphical form to meet the objectives and to aid in interpretation.	14	12	
Ability to discuss the raw and derived data/graphs and assess the validity of the results in relation to the underlying theory and expected trends.	14	12	
Ability to draw appropriate and reasonable conclusions in relations to each of the experimental objectives. One conclusion statement for each objective.	7	7	
Total for Ability to Analyze and Interpret experimental Data	80		

TOTAL FOR THIS LAB		90	
---------------------------	--	-----------	--

Darius Jackson-Rubio
Mechanical Engineering Student
Prairie View, Texas 77445
Cell: 5103818757
E-mail: djacksonrubio@pvamu.edu

Dr. Mingli Han
Measurement Laboratory Instructor
Prairie View A&M University
S. R. Collins Engineering Technology Building
Room 311

September 14, 2021

Dear Dr. Han:

The following pages are a detailed report for lab 1 of MCEG 3011 Measurement Laboratory, "Precise Measurement Using Micrometers & Introduction to Statistical Analysis of Experimental Data". This report addresses the use of micrometers for precise measurements as well as the use of statistical analysis of experimental data using the mean, deviation, the mean deviation, and the standard deviation. The lab was performed on September 7, 2021 and was submitted on September 14, 2021.

If you have any questions or concerns, please call or email me at any time.

Sincerely,

Darius Jackson-Rubio
Enclosure: Lab Report

ABSTRACT

The purpose of this experiment was to use bolts to help learn how to use micrometers and find precise measurements. Once finding the measurements, use the data and put it on a table to find the mean, deviation, and mean deviation of each bolt. Doing all this helps understand how to use data to find information and plot the data onto graphs that can be used to show your results of the experiment.

The method used to do this experiment was the use of the micrometer and understanding how it works and what each part of the tool does. A micrometer has 5 parts to it: anvil, spindle, sleeve, thimble and ratchet. The sleeve and thimble are what you use to find the measurement of whatever is being placed into the micrometer. The object placed into the micrometer is placed between the anvil and the spindle and can be tightened for a more accurate reading with the ratchet.

The results of the tests ran show that bolt 4 had the highest mean of them all while bolt 2 had the lowest mean. Although, bolt 1 had the lowest standard deviation while bolt 4 has the highest standard deviation.

A conclusion that can be made is that the bolt with the highest mean will have the biggest deviation and this can be seen in the data presented in this report.

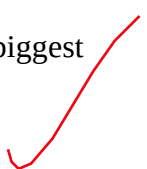


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CHAPTER 1

ABILITY TO CONDUCT EXPERIMENTS

1.1 Objectives of the Experiment

The objectives of the experiment are to:

1. Learn the use of micrometers for precise measurements.
2. Introduce the use of statistical analysis of experimental data using the mean, deviation, the mean deviation and the standard deviation.
3. Plot histograms for a set of experimental data represented by the mean and the standard deviation in the form of $(x_m \pm \sigma)$

1.2 Theory Associated with Experiment

Statistical Analysis of Experimental Data

In many situations, it is necessary to conduct several set of experiments to ensure that the statistical accuracy of the results can be determined. A number of statistical parameters are needed to determine the statistical accuracy of the experimental results. The statistical parameters to be discussed in this section include the mean, the deviation of each data from the mean, the average deviation, and the standard deviation or the root mean square deviation.

The Mean: The mean x_m , of a set of n data in which each data is represented by x_i ($i=1$ to n) is given by

$$x_m = \frac{1}{n} \sum_{i=1}^n x_i \quad (1)$$

The Deviation: The deviation d_i of a set of n data in which each data is represented by x_i ($i=1$ to n) is given by

$$d_i = x_i - x_m \quad (2)$$

Note that the average of the deviations of all the data is zero since the sum of the deviation is zero.

The Mean Deviation: The average of the absolute values of the deviations is however not zero, and is given by

$$\left| \bar{d}_i \right| = \frac{1}{n} \sum |x_i - x_m| \quad (3)$$

The Standard Deviation: The standard deviation is also known as the root mean square deviation. It is one of the most important statistical parameters that is used to ascertain the accuracy as well as the confidence one will have in the value of the measured data. The standard deviation for a very large set of data is given by

$$\sigma = \left[\frac{1}{n} \sum_{i=1}^n (x_i - x_m)^2 \right]^{1/2} \quad (4)$$

When the number of data is not large (smaller than 20 for example), the sample standard deviation is given by

$$\sigma = \left[\frac{\sum (x_i - x_m)^2}{n-1} \right]^{1/2} \quad (5)$$

The Covariance: COV=Standard Deviation/Mean

1.3 Apparatus and Uncertainty in Reading Instruments

The Micrometer

Parts and How to Use a Micrometer [1]

The main parts of the micrometer shown in Figure 1 are the anvil, the spindle, the sleeve the thimble and the ratchet.

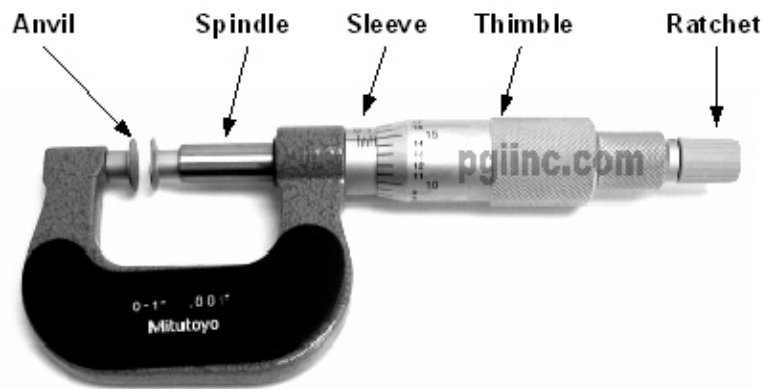


Figure 1 Parts of a Micrometer

Sleeve: The Micrometer sleeve is divided into 10 equal parts, each of these parts is equal to $.100''$ (1 tenth of an inch). Each of these 10 parts is divided into 4 equal parts. Each of these 4 subdivisions is equal to $.025''$ or one 40th of an inch. More simply, the line on the sleeve marked "1" represents $.100''$, the line marked "2" represents $.200''$ and so forth.

Thimble: The thimble is divided into twenty-five equal parts, each of these parts is equal to $.001''$ and, one complete rotation of the thimble coincides with the smallest division ($.025''$) on the sleeve.

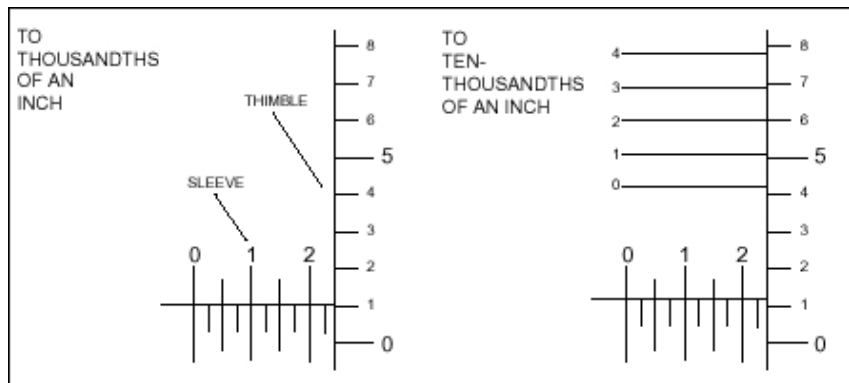


Figure 2 Example Measurements

Taking a Reading on a $.001''$ Micrometer

To read either a $.001''$ or $.0001''$ micrometer, you place the material to be measured between the anvil and spindle, and then turn the ratchet until the spindle closes down and stops moving. Then you read the markings on the sleeve and thimble. In the case of a $.0001''$ micrometer you would then read the markings on the vernier scale to get the $.0001''$ measurement

In our example below, as we take our measurement, we fill in a box for each reading. We suggest you try this method while you are learning to measure with outside micrometers. Soon enough, you will become very fast reading these micrometers

1. *Read the sleeve:*

- In [Figure 2 above](#), when tightening down the thimble on our material, it stopped at a point to the right of "2" on the sleeve, this indicates $.200''$. We wrote this in row (1)

in the table below.

b. There is one line visible between the graduation numbered "2" on the sleeve and the edge of the thimble, this indicates .025". We wrote this in row (2) in the table below.

1. Read the thimble: The graduation numbered "1" on the thimble coincides with the center line of the sleeve. This indicates .001". We wrote this in (3) in the table below.

2. Add it all up: Now just add all the numbers together to determine the thickness of your material.

Table 1 Adding Up

(1) Reading on the Sleeve	.200"
(2) No. of lines between "2" and the edge of the thimble	.025"
(3) Thimble line corresponding to the center line of the	.001"
TOTAL READING	.226"

1.4 Experimental Safety

Some safety precautions that should be taken when running the experiment is to wear closed-toed shoes and keep loose articles of clothing away from the experiment.

1.5 Experimental Procedure

1. Study the information from the information on “**Parts and How to Use a Micrometer**” provided above and from several information available on the web.
2. Identify the four steel bolts numbered 1, 2, 3, 4, and 5 on the bolt-head.
3. Also identify the unthreaded neck portion between the threaded section and the bolt-head.
4. Measure, to 0.001 inch, the diameter at the neck section of the bolt #1 and record your measurement in the personal table provided to you, ensuring that other members in your group do not see your measurement in order to eliminate bias in the measurements.
5. Repeat step 4 for bolts 2, 3, 4, and 5.
6. Steps 1 through 5 should be repeated by each member in the lab group.
7. When all members in the group complete the measurements, the group leader should collect the table from the members of the group and include the group number on the first page.
8. The group leader should submit the results to the course instructor.
9. The course instructor will collect the results from all of the groups.
10. The course instructor will redistribute a set of the results from a group to the group leader in another group.
11. The group leaders should record the data for the group given to the leader on the master table in the classroom before the end of the class.
12. Each student will make a photographic image of the master table containing the entire results or the course instructor will scan and post the master results on e-course for all students to access.

1.6 Presentation of Raw Experimental Data

Table 1.1 Diameters of each bolt

Bolt 1	Bolt 2	Bolt 3	Bolt 4	Bolt 5
0.4310	0.4300	0.4280	0.4330	0.4320
0.4330	0.4320	0.4320	0.4340	0.4330
0.4330	0.4300	0.4320	0.4290	0.4320
0.4310	0.4080	0.4320	0.4330	0.4310
0.4340	0.4330	0.4330	0.4330	0.4340
0.4330	0.4330	0.4320	0.4330	0.4330
0.4332	0.4338	0.4336	0.4322	0.4330
0.4337	0.4346	0.4628	0.4337	0.4339
0.4033	0.4035	0.4036	0.4034	0.4037
0.4316	0.4330	0.4319	0.4319	0.4321
0.4343	0.4332	0.4341	0.4357	0.4351
0.4320	0.4320	0.4330	0.4310	0.4320
0.4320	0.4310	0.4330	0.4320	0.4310
0.4330	0.4350	0.4330	0.4330	0.4330
0.4320	0.4300	0.4290	0.4300	0.4280
0.4290	0.4320	0.4260	0.4280	0.4300
0.4340	0.4330	0.4330	0.4330	0.4330
0.4334	0.4341	0.4337	0.4332	0.4343
0.4338	0.4332	0.4414	0.4329	0.4331
0.4328	0.4331	0.4332	0.5326	0.4330
0.4330	0.4470	0.4200	0.4370	0.4550
0.4330	0.4400	0.4230	0.4340	0.4430



CHAPTER 2

ABILITY TO ANALYZE EXPERIMENTAL DATA

2.1 Detailed Computer Analysis of All Data

Table 2.1 All calculations for each bolt

Unit: inch	Bolt 1	Bolt 2	Bolt 3	Bolt 4	Bolt 5
mean, $\bar{X}_m$	0.431323	0.431114	0.431514	0.435845455	0.432645
Mean Deviation, d_m	0.002817	0.004926	0.005407	0.008900826	0.003819
SDV, σ	0.006231	0.008802	0.009864	0.022054555	0.008239
COV	0.014447	0.020417	0.02286	0.050601778	0.019044

Copy the detailed calculation table to 2.1 section.

Calculation is correct. But this summary table should be in section 2.2

2.2 Presentation of Tables of Derived Results

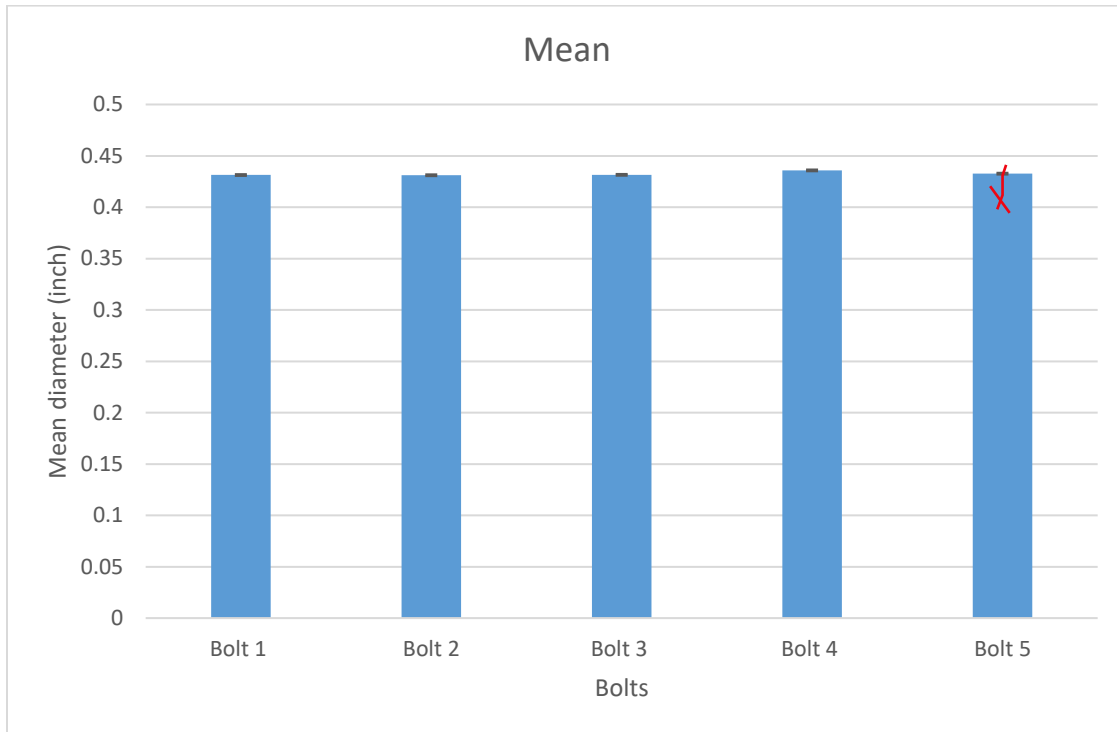
Table 2.2 Derived results of the bolts

Unit: inch	$\bar{X}_m$	d	d^2
Bolt 1	0.431323	0.001165	1.35828E-06
Bolt 2	0.431114	0.001375	1.88938E-06
Bolt 3	0.431514	0.000975	9.49739E-07
Bolt 4	0.435845	0.003357	1.12713E-05
Bolt 5	0.432645	0.000157	2.47347E-08
Sum	2.162441	0.007029	1.54934E-05
N	5	5	5
Mean	0.432488	0.001406	3.09868E-06
STD			0.001760308

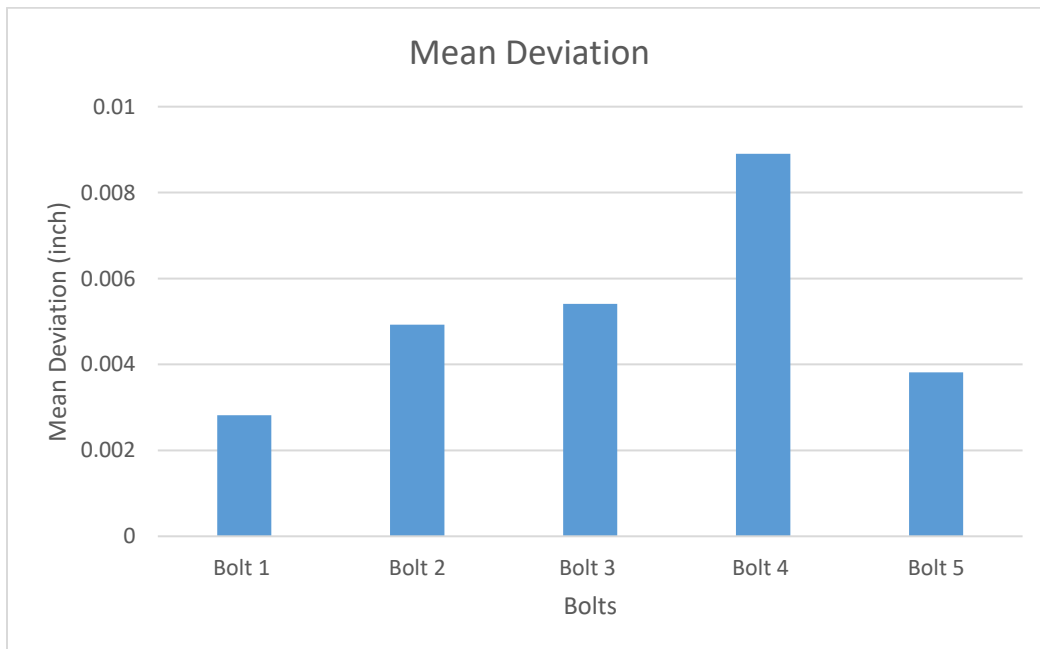
CHAPTER 3

ABILITY TO INTERPRET EXPERIMENTAL DATA

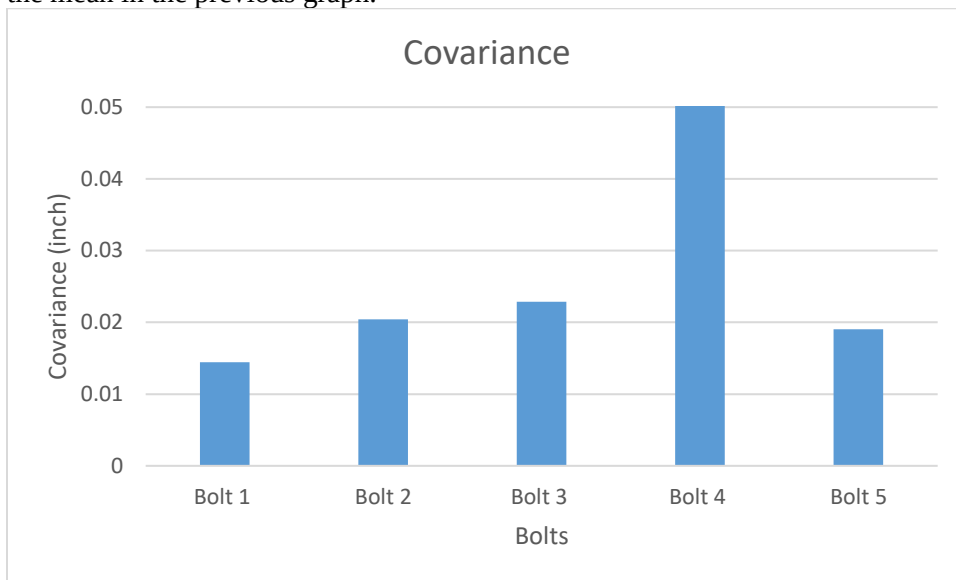
3.1 Presentation of Graphs/Figures and Interpretation of Results Presented by each Graph/Figure



This graph shows the relation of the bolts and their mean diameter which was found using the micrometer. There is also the use of errors bars that can be seen at the top of each bolt.



This graph shows the relation of the bolts and their mean deviation which was based on the calculation of the mean in the previous graph.



The covariance is found by taking the standard deviation of a bolt and dividing it by its mean.

3.2 Conclusions Based on each Objective and the Results

I am now able to use micrometers to find the precise measurement of an object. I was able to use the experimental data to find each component of the lab using statistical analysis of my measurements. I plotted three histograms regarding the bolt's mean, mean deviation, and their covariances.

3.3 Recommendations

Some things that can be done to improve the experiment would be to watch out for the decimal count when taking down data of the bolts and the use of excel numbers and how it uses decimals to get a better number.

AVERAGE

**MECHANICAL ENGINEERING DEPARTMENT
PRAIRIE VIEW A&M UNIVERSITY**



MCEG 3101 MEASUREMENT LABORATORY

Fall 2021 Section P01

LABORATORY REPORT ON

“Measurement Using Micrometers and Statistical Analysis of Data”

**Conducted on
August 24, 2021**

**Submitted by
Christopher Roberts**

**On
September 14, 2021**

To

**Dr. Mingli Han
*Measurement Laboratory Instructor***

**MECHANICAL ENGINEERING DEPARTMENT
MEASUREMENT LABORATORY GRADING SHEET**

FALL 2021 SECTION P01

Title of Experiment: “**Measurement Using Micrometers and Statistical Analysis of Data**”

Name: Christopher Roberts

Date Lab was Performed: 9/7/21

Report Due Date:9/14/21

<i>Ability to Conduct Experiments</i>	MAX	Your Score	Comments
Ability to demonstrate general lab safety (by your conduct and observations).	3	3	
Ability to follow the procedure and properly rephrasing the procedure to reflect what you did during the experiment.	7	7	
Ability to demonstrate knowledge of how equipment function, their limitations, and the uncertainty associated with reading the instruments.	5	5	
Ability to collect and record the raw data using appropriate units of measurement and identify the dependent and independent variables in the experiment.	5	5	
Total for Ability to Conduct Experiments	20	20	
Percentage for this Performance Criteria			
<i>Ability to Analyze and Interpret experimental Data in a Formal Report</i>			
Report format (Ability to properly format and present a technical report)	13	11	
Provides appropriate abstracts for the experimental report	5	5	
Ability to analyze the data using appropriate software to generate the required parameters using consistent units	27	20	
Ability to present the data (raw /derived) in tabular and graphical form to meet the objectives and to aid in interpretation.	14	10	
Ability to discuss the raw and derived data/graphs and assess the validity of the results in relation to the underlying theory and expected trends.	14	3	
Ability to draw appropriate and reasonable conclusions in relations to each of the experimental objectives. One conclusion statement for each objective.	7	7	
Total for Ability to Analyze and Interpret experimental Data	80		
TOTAL FOR THIS LAB		76	

Letter of Transmittal

Christopher Roberts
Mechanical Engineering Student
100 University Dr.
Prairie View, Texas 77446
Cell: (409)338-0850
E-mail: croberts27@pvamu.edu

Dr. Mingli Han
Measurement Laboratory Instructor
Prairie View A&M University
S. R. Collins Engineering Technology Building
Room 311

September 14, 2020

Dear Dr. Han:

The following pages are a detailed report for lab 1 of MCEG 3011 Measurement Laboratory, "Precise Measurement Using Micrometers & Introduction to ~~Statistical~~ Analysis of Experimental Data". This report addresses the use of micrometers for precise measurements as well as the use of statistical analysis of experimental data using the mean, deviation, the mean deviation and the standard deviation. The lab was performed on September 7, 2021 and was submitted on September 14, 2021.

If you have any questions or concerns, please call or email me at any time.

Sincerely,

Christopher Roberts
Enclosure: Lab Report

ABSTRACT

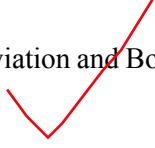
The Purpose of the Experiment

- The purpose of this experiment is to understand how to accurately use a micrometer to measure specific diameters. We will be further interpreting this data by the use of statistical analysis (finding the mean, deviation, the mean deviation and the standard deviation). To assist in visualizing results we will be implementing the use of histograms

The Brief Description of Method Used

- Utilizing micrometers and measuring the diameters of five different bolts

The Significant Results of the Tests

- Results are overall consistent however it is evident that Bolt 4 has a higher mean deviation and Bolt 1 has higher covariance.
- 

The Major Conclusions Drawn from the Results

- All of the bolts are very similar, with low deviations from the mean.

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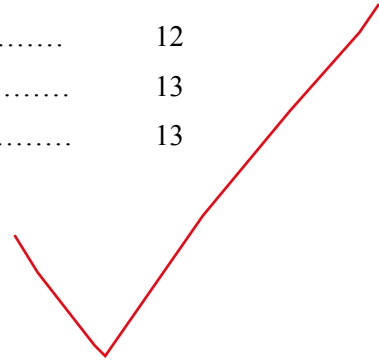
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CHAPTER 1

ABILITY TO CONDUCT EXPERIMENTS

1.1 Objectives of the Experiment

The objectives of the experiment are to:

1. Learn the use of micrometers for precise measurements.
2. Introduce the use of statistical analysis of experimental data using the mean, deviation, the mean deviation and the standard deviation.
3. Plot histograms for a set of experimental data represented by the mean and the standard deviation in the form of $(x_m \pm \sigma)$

you may move up 1.2 section to fill the empty space



1.2 Theory Associated with Experiment

Statistical Analysis of Experimental Data

In many situations, it is necessary to conduct several set of experiments to ensure that the statistical accuracy of the results can be determined. A number of statistical parameters are needed to determine the statistical accuracy of the experimental results. The statistical parameters to be discussed in this section include the mean, the deviation of each data from the mean, the average deviation, and the standard deviation or the root mean square deviation.

The Mean: The mean x_m of a set of n data in which each data is represented by x_i ($i=1$ to n) is given by

$$x_m = \frac{1}{n} \sum_{i=1}^n x_i \quad (1)$$

The Deviation: The deviation d_i of a set of n data in which each data is represented by x_i ($i=1$ to n) is given by

$$d_i = x_i - x_m \quad (2)$$

Note that the average of the deviations of all the data is zero since the sum of the deviation is zero.

The Mean Deviation: The average of the absolute values of the deviations is however not zero, and is given by

$$\bar{d}_i = \frac{1}{n} \sum |x_i - x_m| \quad (3)$$

The Standard Deviation: The standard deviation is also known as the root mean square deviation. It is one of the most important statistical parameters that is used to ascertain the accuracy as well as the confidence one will have in the value of the measured data. The standard deviation for a very large set of data is given by

$$\sigma = \left[\frac{1}{n} \sum_{i=1}^n (x_i - x_m)^2 \right]^{1/2} \quad (4)$$

When the number of data is not large (smaller than 20 for example), the sample standard deviation is given by

$$\sigma = \left[\frac{\sum (x_i - x_m)^2}{n-1} \right]^{1/2} \quad (5)$$

The Covariance: COV=Standard Deviation/Mean

1.3 Apparatus and Uncertainty in Reading Instruments

The Micrometer

Parts and How to Use a Micrometer [1]

The main parts of the micrometer shown in Figure 1 are the anvil, the spindle, the sleeve, the thimble and the ratchet.

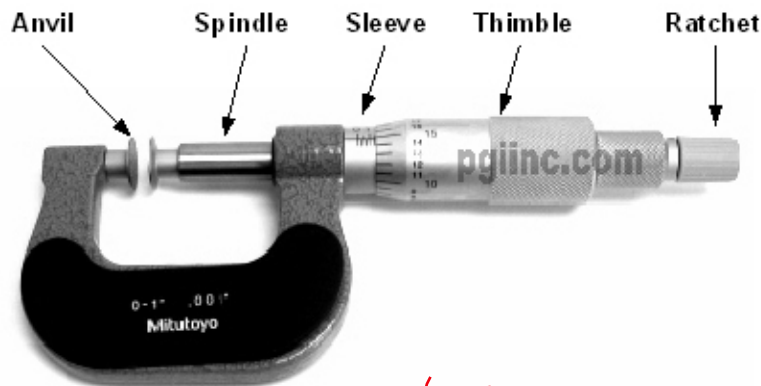


Figure 1 Parts of a Micrometer

Sleeve: The Micrometer sleeve is divided into 10 equal parts, each of these parts is equal to $.100''$ (1 tenth of an inch). Each of these 10 parts is divided into 4 equal parts. Each of these 4 subdivisions is equal to $.025''$ or one 40th of an inch. More simply, the line on the sleeve marked "1" represents $.100''$, the line marked "2" represents $.200''$ and so forth.

Thimble: The thimble is divided into twenty-five equal parts, each of these parts is equal to $.001''$ and, one complete rotation of the thimble coincides with the smallest division ($.025''$) on the sleeve.

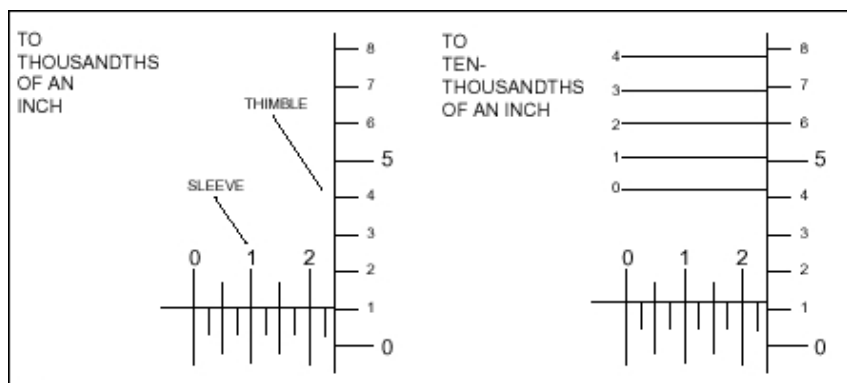


Figure 2 Example Measurements

Taking a Reading on a $.001''$ Micrometer

To read either a $.001''$ or $.0001''$ micrometer, you place the material to be measured between the anvil and spindle, and then turn the ratchet until the spindle closes down and stops moving. Then you read the markings on the sleeve

and thimble. In the case of a .0001" micrometer you would then read the markings on the vernier scale to get the .0001" measurement

In our example below, as we take our measurement, we fill in a box for each reading. We suggest you try this method while you are learning to measure with outside micrometers. Soon enough, you will become very fast reading these micrometers

1. Read the sleeve:

a. In [Figure 2 above](#), when tightening down the thimble on our material, it stopped at a point to the right of "2" on the sleeve, this indicates .200". We wrote this in row (1) in the table below.

b. There is one line visible between the graduation numbered "2" on the sleeve and the edge of the thimble, this indicates .025". We wrote this in row (2) in the table below.

1. Read the thimble: The graduation numbered "1" on the thimble coincides with the center line of the sleeve. This indicates .001". We wrote this in (3) in the table below.

2. Add it all up: Now just add all the numbers together to determine the thickness of your material.

Table 1 Adding Up

(1) Reading on the Sleeve	.200"
(2) No. of lines between "2" and the edge of the thimble	.025"
(3) Thimble line corresponding to the center line of the	.001"
TOTAL READING	.226"

1.4 Experimental Safety

1. “Horseplay” is hazardous and will not be tolerated.
2. No student may work alone in the laboratory at any time except to prepare flow diagrams and operating procedures. When hazardous operations are conducted, arrangements should be made to have another individual present in the lab.
3. Required personal protective equipment (PPE) must be provided by the department used whenever specified by the Laboratory Director/Technician.
4. Always wear appropriate clothing (e.g. shirts, shoes) and personal protective equipment(e.g. safety glasses, lab coats, gloves) in the laboratory. Remove personal protective equipment before leaving the laboratory.
5. Sandals, open-toed shoes, high-heeled shoes, and shoes (or boots) with holes in the soles or having canvas uppers will not be worn in the laboratory. Shirts or blouses are required in the laboratories. Shorts and skirts are not permitted.
6. Each student MUST know the use and location of all first aid and emergency equipment in the laboratories, shops, and storage areas.
7. Each student must know the emergency telephone numbers to summon the fire fighters, police, emergency medical service or other emergency response services. These numbers MUST be posted at many places throughout the building.
8. Each student must be familiar with all elements of fire safety: alarm, evacuation and assembly, fire containment and suppression, rescue and facilities evaluation.

1.5 Experimental Procedure

1. The information from “**Parts and How to Use a Micrometer**” and from several information available on the web was studied.
2. The four steel bolts numbered 1, 2, 3, 4, and 5 were identified on the bolt head.
3. The unthreaded neck portion between the threaded section and the bolt-head was identified.
4. The diameter at the neck section of the bolt #1 was measured, to 0.001 inch, and the measurement was recorded in the personal table provided to me, while ensuring that other members in your group did not see my measurements in order to eliminate bias.
5. Step 4 was repeated for bolts 2, 3, 4, and 5.
6. Steps 1 through 5 were repeated by each member in the lab group.
7. When all members in the group completed the measurements, the group leader collected the table from the members of the group and included the group number on the first page.
8. The group leader submitted the results to the course instructor.
9. The course instructor collected the results from all of the groups.
10. The course instructor redistributed a set of the results from a group to the group leader in another group.
11. The group leaders recorded the data for the group given to the leader on the master table in the classroom before the end of the class.
12. The course instructor scanned and posted the master results on e-course for all students to access.

1.6 Presentation of Raw Experimental Data

Table 2 Raw Data

	Bolt 1	Bolt 2	Bolt 3	Bolt 4	Bolt 5
Group 1	0.4310	0.4300	0.4280	0.4330	0.4320
	0.4330	0.4320	0.4320	0.4340	0.4330
	0.4330	0.4300	0.4320	0.4290	0.4320
	0.4310	0.4080	0.4320	0.4330	0.4310
	0.4340	0.4330	0.4330	0.4330	0.4340
Group 2	0.4330	0.4330	0.4320	0.4330	0.4330
	0.4332	0.4338	0.4336	0.4322	0.4330
	0.4337	0.4346	0.4628	0.4337	0.4339
	0.4033	0.4035	0.4036	0.4034	0.4037
	0.4316	0.4330	0.4319	0.4319	0.4321
	0.4343	0.4332	0.4341	0.4357	0.4351
Group 3	0.4320	0.4320	0.4330	0.4310	0.4320
	0.4320	0.4310	0.4330	0.4320	0.4310
	0.4330	0.4350	0.4330	0.4330	0.4330
	0.4320	0.4300	0.4290	0.4300	0.4280
	0.4290	0.4320	0.4260	0.4280	0.4300
	0.4340	0.4330	0.4330	0.4330	0.4330
Group 4	0.4334	0.4341	0.4337	0.4332	0.4343
	0.4338	0.4332	0.4414	0.4329	0.4331
	0.4328	0.4331	0.4332	0.5326	0.4330
	0.4330	0.4470	0.4200	0.4370	0.4550
	0.4330	0.4400	0.4230	0.4340	0.4430



CHAPTER 2 ABILITY TO ANALYZE EXPERIMENTAL DATA

2.1

2.1 Detailed Computer Analysis of All Data

Table 1 Bolt 1 Data

	Bolt 1	Deviation	Deviation^2
	0.4310	0.0003	0.000000104152892562
	0.4330	0.0017	0.000002813243801653
	0.4330	0.0017	0.000002813243801653
	0.4310	0.0003	0.000000104152892562
	0.4340	0.0027	0.000007167789256198
	0.4330	0.0017	0.000002813243801653
	0.4332	0.0019	0.000003524152892562
	0.4337	0.0024	0.000005651425619834
	0.4033	0.0280	0.000785273243801655
	0.4316	0.0003	0.000000076880165289
	0.4343	0.0030	0.000008864152892562
	0.4320	0.0007	0.000000458698347107
	0.4320	0.0007	0.000000458698347107
	0.4330	0.0017	0.000002813243801653
	0.4320	0.0007	0.000000458698347107
	0.4290	0.0023	0.000005395061983471
	0.4340	0.0027	0.000007167789256198
	0.4334	0.0021	0.000004315061983471
	0.4338	0.0025	0.00000613688016529
	0.4328	0.0015	0.000002182334710744
	0.4330	0.0017	0.000002813243801653
	0.4330	0.0017	0.000002813243801653
Sum:	9.4891	6.20E-02	0.000854218636363637
N:	22	22	22
Mean:	0.4313	2.82E-03	3.88E-05
STD:			6.23E-03
COV:			160.4821815

Table 2 Bolt 2 Data

	Bolt 2	Deviation	Deviation^2
	0.4300	0.0011	0.000001240185950413
	0.4320	0.0009	0.000000785640495868
	0.4300	0.0011	0.000001240185950413
	0.4080	0.0231	0.000534240185950412
	0.4330	0.0019	0.000003558367768595
	0.4330	0.0019	0.000003558367768595
	0.4338	0.0027	0.000007216549586777
	0.4346	0.0035	0.000012154731404959
	0.4035	0.0276	0.000762512913223136
	0.4330	0.0019	0.000003558367768595
	0.4332	0.0021	0.000004352913223141
	0.4320	0.0009	0.000000785640495868
	0.4310	0.0001	0.000000012913223140
	0.4350	0.0039	0.000015103822314050
	0.4300	0.0011	0.000001240185950413
	0.4320	0.0009	0.000000785640495868
	0.4330	0.0019	0.000003558367768595
	0.4341	0.0030	0.000008918367768595
	0.4332	0.0021	0.00000435291322314
	0.4331	0.0020	0.000003945640495868
	0.4470	0.0159	0.000252376549586779
	0.4400	0.0089	0.000078967458677687
Sum:	9.4845	1.08E-01	0.001704465909090910
N:	22	22	22
Mean:	0.4311	4.93E-03	7.75E-05
STD:			8.80E-03
COV:			113.6101624

Table 3 Bolt 3 Data

	Bolt 3	Deviation	Deviation^2
	0.4280	0.0035	0.000012345640495868
	0.4320	0.0005	0.000000236549586777
	0.4320	0.0005	0.000000236549586777
	0.4320	0.0005	0.000000236549586777
	0.4330	0.0015	0.000002209276859504
	0.4320	0.0005	0.000000236549586777
	0.4336	0.0021	0.000004352913223141
	0.4628	0.0313	0.000978836549586779
	0.4036	0.0279	0.000779171095041319
	0.4319	0.0004	0.000000149276859504
	0.4341	0.0026	0.000006689276859504
	0.4330	0.0015	0.000002209276859504
	0.4330	0.0015	0.000002209276859504
	0.4330	0.0015	0.000002209276859504
	0.4290	0.0025	0.000006318367768595
	0.4260	0.0055	0.000030400185950413
	0.4330	0.0015	0.000002209276859504
	0.4337	0.0022	0.000004780185950413
	0.4414	0.0099	0.00009774018595041
	0.4332	0.0017	0.000002843822314050
	0.4200	0.0115	0.000132563822314049
	0.4230	0.0085	0.000072482004132231
Sum:	9.4933	1.19E-01	0.002140665909090910
N:	22	22	22
Mean:	0.4315	5.41E-03	9.73E-05
STD:			9.86E-03
COV:			101.3764068

Table 4 Bolt 4 Data

	Bolt 4	Deviation	Deviation^2
	0.4330	0.0028	0.000008096611570247
	0.4340	0.0018	0.000003405702479338
	0.4290	0.0068	0.000046860247933883
	0.4330	0.0028	0.000008096611570247
	0.4330	0.0028	0.000008096611570247
	0.4330	0.0028	0.000008096611570247
	0.4322	0.0036	0.000013289338842975
	0.4337	0.0021	0.000004602975206611
	0.4034	0.0324	0.001052707520661150
	0.4319	0.0039	0.000015566611570247
	0.4357	0.0001	0.000000021157024793
	0.4310	0.0048	0.000023478429752065
	0.4320	0.0038	0.000014787520661156
	0.4330	0.0028	0.000008096611570247
	0.4300	0.0058	0.000034169338842974
	0.4280	0.0078	0.000061551157024792
	0.4330	0.0028	0.000008096611570247
	0.4332	0.0026	0.000006998429752066
	0.4329	0.0029	0.00000867570247934
	0.5326	0.0968	0.009361442066115720
	0.4370	0.0012	0.000001332975206612
	0.4340	0.0018	0.000003405702479338
Sum:	9.5886	1.96E-01	0.010700874545454500
N:	22	22	22
Mean:	0.4358	8.90E-03	4.86E-04
STD:			2.21E-02
COV:			45.3421077

Table 5 Bolt 5 Data

	Bolt 5	Deviation	Deviation^2
	0.4320	0.0006	0.000000416611570248
	0.4330	0.0004	0.000000125702479339
	0.4320	0.0006	0.000000416611570248
	0.4310	0.0016	0.000002707520661157
	0.4340	0.0014	0.000001834793388430
	0.4330	0.0004	0.000000125702479339
	0.4330	0.0004	0.000000125702479339
	0.4339	0.0013	0.000001573884297521
	0.4037	0.0289	0.000837839338842976
	0.4321	0.0005	0.000000297520661157
	0.4351	0.0025	0.000006024793388430
	0.4320	0.0006	0.000000416611570248
	0.4310	0.0016	0.000002707520661157
	0.4330	0.0004	0.000000125702479339
	0.4280	0.0046	0.000021580247933885
	0.4300	0.0026	0.000006998429752066
	0.4330	0.0004	0.000000125702479339
	0.4343	0.0017	0.000002737520661157
	0.4331	0.0005	0.00000020661157025
	0.4330	0.0004	0.000000125702479339
	0.4550	0.0224	0.000499725702479339
	0.4430	0.0104	0.000107216611570248
Sum:	9.5182	8.40E-02	0.001493454545454550
N:	22	22	22
Mean:	0.4326	3.82E-03	6.79E-05
STD:			8.24E-03
COV:			121.3711134

2.2 Presentation of Tables of Derived Results

Table 6 Summary of Computed Results

	Bolt 1	Bolt 2	Bolt 3	Bolt 4	Bolt 5
Mean	0.4313	0.4311	0.4315	0.4358	0.4326
Mean Deviation	2.82E-03	4.93E-03	5.41E-03	8.90E-03	3.82E-03
STD	0.00623122	0.008802029	0.00986423	0.02205456	0.00823919
COV	160.482182	113.6101624	101.376407	45.3421077	121.371113



Table 7 Computed Results for Five Bolts

	Mean	Mean Deviation	Deviation^2
Bolt 1	0.4313	2.82E-03	3.88E-05
Bolt 2	0.4311	4.93E-03	7.75E-05
Bolt 3	0.4315	5.41E-03	9.73E-05
Bolt 4	0.4358	8.90E-03	4.86E-04
Bolt 5	0.4326	3.82E-03	6.79E-05
N	5	5	5
MEAN	0.4325	5.18E-03	1.54E-04
STD	1.96E-03	1.11E-02	1.87E-04

CHAPTER 3

ABILITY TO INTERPRET EXPERIMENTAL DATA

3.1 Presentation of Graphs/Figures and Interpretation of Results Presented by each Graph/Figure

Figure 1: Mean
Mean

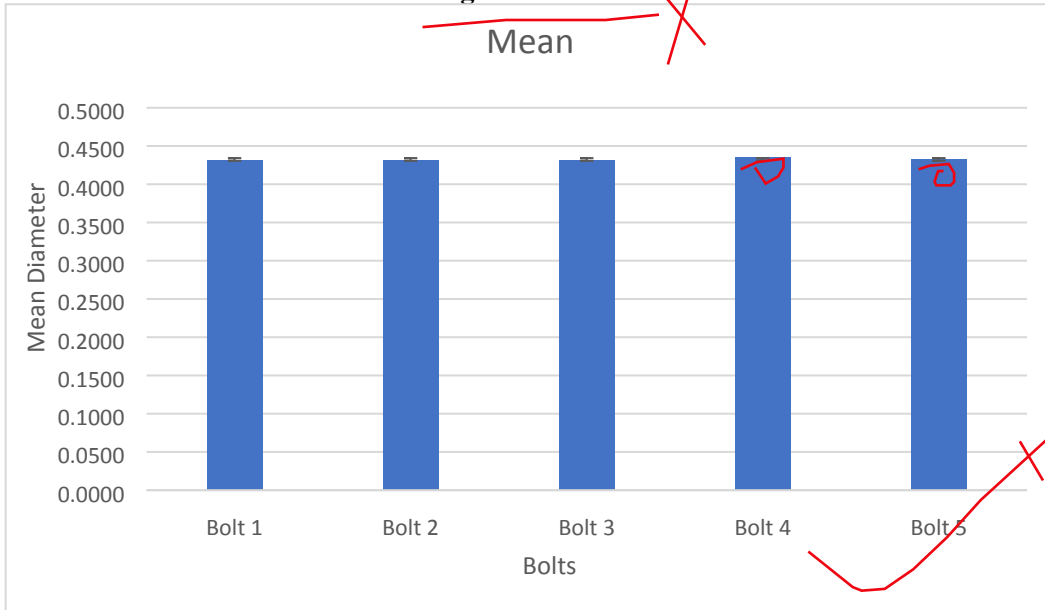


Figure 2: Mean Deviation

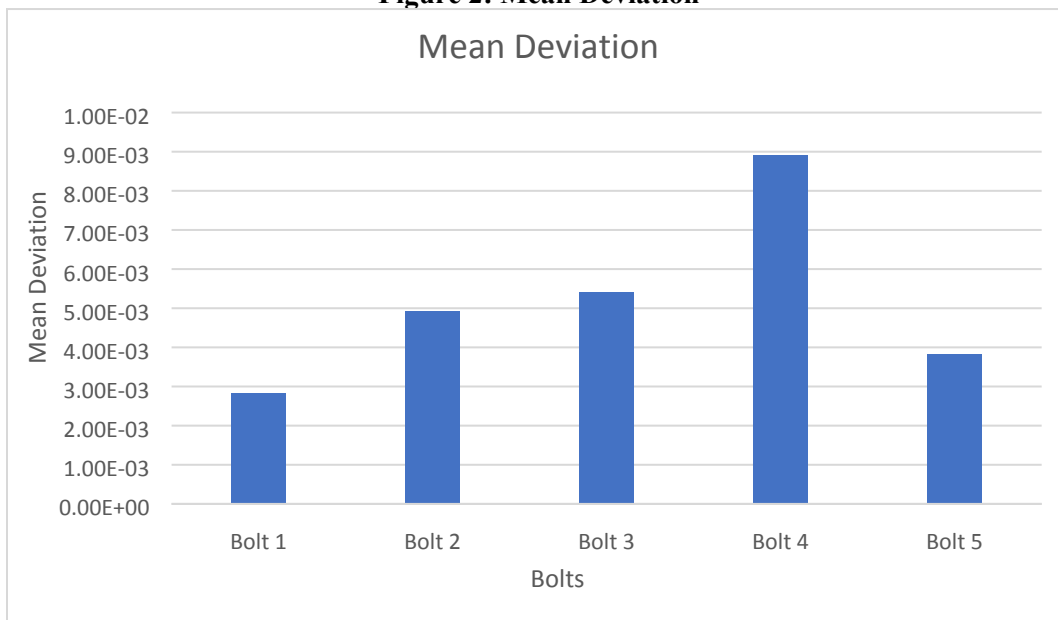
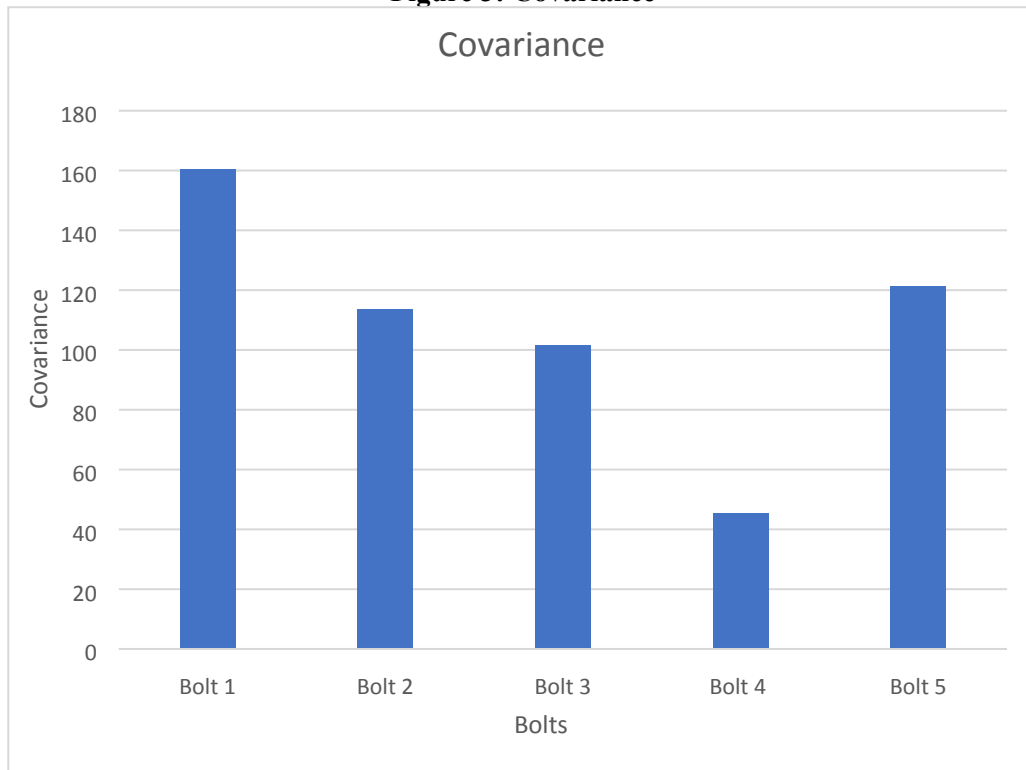


Figure 3: Covariance



3.2 Conclusions Based on each Objective and the Results

- Successfully learned how to use micrometer for precise measurements.
- Successfully introduced the use of statistical analysis of experimental data using the mean, deviation, the mean deviation and the standard deviation.
- Successfully plotted histograms for a set of experimental data represented by the mean and the standard deviation in the form of $(x_m \pm \sigma)$

3.3 Recommendations

Now that I have successfully learned how to measure with a micrometer and use statistical analysis I can use these skills to help me with the rest of this course. Experimental results can be improved by using skills learned during this lab to ensure that I am using the measuring device correctly

BELOW AVERAGE



MCEG 3101

Lab 1 Report

"Introduction to Statistical Analysis of Experimental Data"

By: Devan Mitchell

Objectives:

The objectives of the experiment are to:

1. Learn the use of micrometers for precise measurements.
2. Introduce the use of statistical analysis of experimental data using the mean, deviation, the mean deviation and the standard deviation.
3. Plot histograms for a set of experimental data represented by the mean and the standard deviation in the form of $(x_m \pm \sigma)$

Theory:

Statistical Analysis of Experimental Data

In many situations, it is necessary to conduct several sets of experiments to ensure that the statistical accuracy of the results can be determined. Several statistical parameters are needed to determine the statistical accuracy of the experimental results. The statistical parameters to be discussed in this section include the mean, the deviation of each data from the mean, the average deviation, and the standard deviation or the root mean square deviation.

The Mean: The mean x_m of a set of n data in which each data is represented by x_i ($i=1$ to n) is given by

$$x_m = \frac{1}{n} \sum_{i=1}^n x_i \quad (1)$$

The Deviation: The deviation d_i of a set of n data in which each data is represented by x_i ($i=1$ to n) is given by

$$d_i = x_i - x_m \quad (2)$$

Note that the average of the deviations of all the data is zero since the sum of the deviation is zero.

The Mean Deviation: The average of the absolute values of the deviations is however not zero, and is given by

$$\left| \bar{d}_i \right| = \frac{1}{n} \sum |x_i - x_m| \quad (3)$$

The Standard Deviation: The standard deviation is also known as the root mean square deviation. It is one of the most important statistical parameters that is used to ascertain the accuracy as well as the confidence one will have in the value of the measured data. The standard deviation for a very large set of data is given by

$$\sigma = \left[\frac{1}{n} \sum_{i=1}^n (x_i - x_m)^2 \right]^{1/2} \quad (4)$$

When the number of data is not large (smaller than 20 for example), the sample standard deviation is

given by

$$\sigma = \left[\frac{\sum (x_i - x_m)^2}{n-1} \right]^{1/2} \quad (5)$$

The Covariance: COV=Standard Deviation/Mean

Procedure:

1. Study the information from the information on **“Parts and How to Use a Micrometer”** provided above and from several information available on the web.
2. Identify the four steel bolts numbered 1, 2, 3, 4, and 5 on the bolt-head.
3. Also identify the unthreaded neck portion between the threaded section and the bolt-head.
4. Measure, to 0.001 inch, the diameter at the neck section of the bolt #1 and record your measurement in the personal table provided to you, ensuring that other members in your group do not see your measurement in order to eliminate bias in the measurements.
5. Repeat step 4 for bolts 2, 3, 4, and 5.
6. Steps 1 through 5 should be repeated by each member in the lab group.
7. When all members in the group complete the measurements, the group leader should collect the table from the members of the group and include the group number on the first page.
8. The group leader should submit the results to the course instructor.
9. The course instructor will collect the results from all the groups.
10. The course instructor will redistribute a set of the results from a group to the group leader in another group.
11. The group leaders should record the data for the group given to the leader on the master table in the classroom before the end of the class.
12. Each student will make a photographic image of the master table containing the entire results or the course instructor will scan and post the master results on e-course for all students to access.

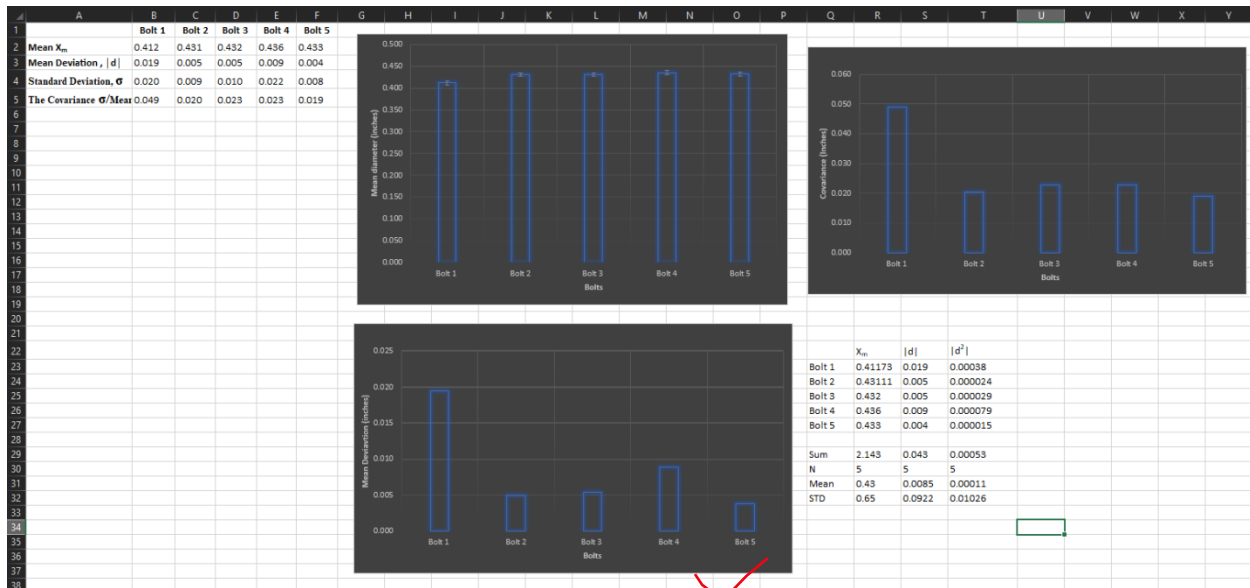
Table 2 Raw Experimental Data:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1	Name	Bolt 1	d	d ²		Bolt 2	d	d ²		Bolt 3	d	d ²		Bolt 4	d	d ²		Bolt 5	d	d ²
2		0.4310	0.0193	0.0004		0.4300	0.0011	0.0000		0.4280	0.0035	0.0000		0.4330	0.0028	0.0000		0.4320	0.0006	0.00000042
3		0.4330	0.0213	0.0005		0.4320	0.0009	0.0000		0.4320	0.0005	0.0000		0.4340	0.0018	0.0000		0.4330	0.0004	0.00000013
4		0.4330	0.0213	0.0005		0.4300	0.0011	0.0000		0.4320	0.0005	0.0000		0.4290	0.0068	0.0000		0.4320	0.0006	0.00000042
5		0.4310	0.0193	0.0004		0.4080	0.0231	0.0005		0.4320	0.0005	0.0000		0.4330	0.0028	0.0000		0.4310	0.0016	0.00000271
6		0.4340	0.0223	0.0005		0.4330	0.0019	0.0000		0.4330	0.0015	0.0000		0.4330	0.0028	0.0000		0.4340	0.0014	0.00000183
7		0.4330	0.0213	0.0005		0.4330	0.0019	0.0000		0.4320	0.0005	0.0000		0.4330	0.0028	0.0000		0.4330	0.0004	0.00000013
8		0.4332	0.0215	0.0005		0.4338	0.0027	0.0000		0.4336	0.0021	0.0000		0.4322	0.0036	0.0000		0.4330	0.0004	0.00000013
9		0.4337	0.0220	0.0005		0.4346	0.0035	0.0000		0.4628	0.0313	0.0010		0.4337	0.0021	0.0000		0.4339	0.0013	0.00000157
10		0.4033	0.0084	0.0001		0.4035	0.0276	0.0008		0.4036	0.0279	0.0008		0.4034	0.0324	0.0011		0.4037	0.0289	0.00083784
11		0.4316	0.0199	0.0004		0.4330	0.0019	0.0000		0.4319	0.0004	0.0000		0.4319	0.0039	0.0000		0.4321	0.0005	0.00000030
12		0.4343	0.0226	0.0005		0.4332	0.0021	0.0000		0.4341	0.0026	0.0000		0.4357	0.0001	0.0000		0.4351	0.0025	0.00000602
13		0.4320	0.0203	0.0004		0.4320	0.0009	0.0000		0.4330	0.0015	0.0000		0.4310	0.0048	0.0000		0.4320	0.0006	0.00000042
14		0.4320	0.0203	0.0004		0.4310	0.0001	0.0000		0.4330	0.0015	0.0000		0.4320	0.0038	0.0000		0.4310	0.0016	0.00000271
15		0.4330	0.0213	0.0005		0.4350	0.0039	0.0000		0.4330	0.0015	0.0000		0.4330	0.0028	0.0000		0.4330	0.0004	0.00000013
16		0.4320	0.0203	0.0004		0.4300	0.0011	0.0000		0.4290	0.0025	0.0000		0.4300	0.0058	0.0000		0.4280	0.0046	0.00002158
17		0.4290	0.0173	0.0003		0.4320	0.0009	0.0000		0.4260	0.0055	0.0000		0.4280	0.0078	0.0001		0.4300	0.0026	0.00000700
18		0.4340	0.0223	0.0005		0.4330	0.0019	0.0000		0.4330	0.0015	0.0000		0.4330	0.0028	0.0000		0.4330	0.0004	0.00000013
19		0.4334	0.0217	0.0005		0.4341	0.0030	0.0000		0.4337	0.0022	0.0000		0.4332	0.0026	0.0000		0.4343	0.0017	0.00000274
20		0.4338	0.0221	0.0005		0.4332	0.0021	0.0000		0.4414	0.0099	0.0001		0.4329	0.0029	0.0000		0.4331	0.0005	0.00000021
21		0.4328	0.0211	0.0004		0.4331	0.0020	0.0000		0.4332	0.0017	0.0000		0.5326	0.0968	0.0094		0.4330	0.0004	0.00000013
22		0.4330	0.0213	0.0005		0.4470	0.0159	0.0003		0.4200	0.0115	0.0001		0.4370	0.0012	0.0000		0.4550	0.0224	0.00049973
23		0.4330	0.0213	0.0005		0.4400	0.0089	0.0001		0.4230	0.0085	0.0001		0.4340	0.0018	0.0000		0.4430	0.0104	0.00010722
24																				
25	SUM	9.0581	0.4286	0.0089		9.4845	0.1084	0.0017		9.4933	0.1190	0.0021		9.5886	0.1958	0.0107		9.5182	0.0840	0.0045
26	N	22	22	22		22	22	22		22	22	22		22	22	22		22	22	22
27	Mean	0.4117	0.0195	0.0004		0.4311	0.0049	0.0001		0.4315	0.0054	0.0001		0.4358	0.0089	0.0005		0.4326	0.0038	0.0001
28	SDV			0.0201				0.0088				0.0099				0.0221				0.0082
29	COV			0.0489				0.0204				0.0229				0.0506				0.0190

Analysis and Lab Report:

For this lab you can demonstrate your understanding of the statistical analysis discussed in the theory using Excel. However, you are not allowed to use the built-in functions to compute any of the statistical variables in the theory section.

1. For the set of data for bolt 1, compute the sum using the sum function of excel
2. Using the amount of data in the set and the sum, compute the mean using equation 1.
3. In a column next to the data column for Bolt 1, compute the absolute value of the deviation of each data from the mean using equation 2 in the absolute value sense.
4. Compute the mean deviation for the measurements for Bolt 1 using equation 3.
5. In a column next to the absolute deviation column, compute the squares of the deviations, i.e. $(x_i - x_m)^2$.
6. Compute the standard deviation using equation 4 or 5, whichever is applicable.
7. Repeat steps 1 through 6 for bolts 2, 3, 4, and 5.
8. Summarize your results for the five bolts in a table like the one below in excel.



Report:

During this lab we perform numerous measurements using a micrometer. Once we had the measurement for the five bolts, we performed calculations to find the sum, mean, mean deviation, standard deviation, and covariance for all five bolts. I was able to use Excel to find all the calculation after getting the raw data from measuring the bolts. To find the standard deviation I use the formula

$$\sigma = \left[\frac{1}{n} \sum_{i=1}^n (x_i - x_m)^2 \right]^{1/2}$$

and, to find the covariance you would simply divide the standard deviation by the mean

of the data. I would say this lab was a successful since I was able to correctly answer ever question in the lab and also since the error percentage was less than ten precent meaning that the measurements was near the same.

**MEASUREMENT AND INSTRUMENTATION LABORATORY
FALL 2021**

LABORATORY REPORT # 2

TOPICS COVERED IN LABORATORY EXPERIMENT #2

**EXPERIMENT #2
STATISTICAL ANALYSIS OF DATA ON LINEAR MEASUREMENT
USING VERNIER CALIPERS AND AREA MEASUREMENT USING
PLANIMETER**

The objectives of the experiment are to:

- 1. Learn the use of Vernier calipers and planimeter for precise measurements.**
- 2. Introduce the use of statistical analysis and Chauvenets Criteria of experimental data using the mean, deviation, the mean deviation and the standard deviation.**
- 3. Plot histograms for a set of experimental data represented by the mean and the standard deviation in the form of $(x_m \pm \sigma)$**

**MEASUREMENT AND INSTRUMENTATION LABORATORY
FALL 2021**

LABORATORY HANDOUT FOR EXPERIMENT 2

**STATISTICAL ANALYSIS OF DATA ON LINEAR MEASUREMENT
USING VERNIER CALIPERS AND AREA MEASUREMENT USING
PLANIMETER**

Statistical Analysis of Data on Linear Measurement Using Dial Calipers and Area Measurement Using Planimeter

Objectives:

The objectives of the experiment are to:

1. Learn the use of Vernier calipers and planimeter for precise measurements.
2. Introduce the use of statistical analysis and Chauvenets Criteria of experimental data using the mean, deviation, the mean deviation and the standard deviation.
3. Plot histograms for a set of experimental data represented by the mean and the standard deviation in the form of $(x_m \pm \sigma)$

Theory

Statistical Analysis of Experimental Data

In many situations, it is necessary to conduct several set of experiments to ensure that the statistical accuracy of the results can be determined. A number of statistical parameters are needed to determine the statistical accuracy of the experimental results. The statistical parameters to be discussed in this section include the mean, the deviation of each data from the mean, the average deviation, and the standard deviation or the root mean square deviation.

The Mean: The mean x_m , of a set of n data in which each data is represented by x_i ($i=1$ to n) is given by

$$x_m = \frac{1}{n} \sum_{i=1}^n x_i \quad (1)$$

The Deviation: The deviation d_i of a set of n data in which each data is represented by x_i ($i=1$ to n) is given by

$$d_i = x_i - x_m \quad (2)$$

Note that the average of the deviations of all the data is zero since the sum of the deviation is zero.

The Mean Deviation: The average of the absolute values of the deviations is however not zero, and is given by

$$\bar{d}_i = \frac{1}{n} \sum |x_i - x_m| \quad (3)$$

The Standard Deviation: The standard deviation is also known as the root mean square deviation. It is one of the most important statistical parameters that are used to ascertain the accuracy as well as the confidence one will have in the value of the measured data. The standard deviation for a very large set of data is given by

$$\sigma = \left[\frac{1}{n} \sum_{i=1}^n (x_i - x_m)^2 \right]^{1/2} \quad (4)$$

When the number of data is not large (less than 20 for example), the sample standard deviation is given by

$$\sigma = \left[\frac{\sum (x_i - x_m)^2}{n-1} \right]^{1/2} \quad (5)$$

The Covariance: $COV = \text{Standard Deviation} / \text{Mean}$

Chauvenets Criterion for Rejecting Data

There are instances when an experimenter would have data that that appears to be bad or out of place in comparison to the other data. When this occurs, a decision has to be made as to whether this was caused by some type of experimental blunder and thus should be neglected or that the data was the result of an unknown physical phenomenon. To answer this problem, we need to first calculate the standard deviation of the set of data including the data in question and then analyze the data using the Gaussian or Normal

distribution function. The normal distribution function $P(x_m)$ gives the probability that a measurement x , will lie between x_m+x_1 and x_m-x_1 , where x_m is the mean of the set of data. $P(x_1)$ is given by

$$P(x_1) = \int_{x_m-x_1}^{x_m+x_1} \frac{1}{\sigma\sqrt{2\pi}} e^{-(x-x_m)^2/2\sigma^2} dx \quad (14)$$

With a change of variables $\eta = \frac{x-x_m}{\sigma}$

$$P(\eta_1) = \int_{-\eta_1}^{\eta_1} \frac{1}{\sigma\sqrt{2\pi}} e^{-\eta^2/2} d\eta \quad (15)$$

With this probability function, we can calculate the probability for a data to fall within 1,2,3,4,5 etc. standard deviations from the mean, as well as the probability for the data to fall outside these deviations from the mean. Table 1.1 gives these probabilities.

Table 1.1 Probability of a Data Falling Within Specified Number of Standard Deviations

Number of Standard Deviations	Probability of Data falling within the number of standard deviations	Probability of data falling outside the number of standard deviations
1	0.68268	0.31732
2	0.95450	0.0455
3	0.9973	0.0027
4	0.9999366	0.0000634

From the table, it is seen that it becomes highly unlikely for data to fall outside of very large standard deviations from the mean. This information can be used to detect data that may be bad. Obviously, the likelihood of a data falling several standard deviations outside the mean is very small and this can be an indicator that the data is bad.

A standard way of using this strategy to detect bad data is through the application of Chauvenet's criterion. Chauvenet's criterion states that a reading may be rejected if the probability of obtaining the particular deviation from the mean is less than $1/2n$, where n is the number of readings. Using this criterion and the normal probability distribution function, for any number of experimental data, n , the maximum acceptable deviation from the mean can be determined as presented in Table 1.2

Table 1.2 Maximum Acceptable Deviation Ratio as a Function of the Number of Readings

Number of Readings	Ratio of maximum acceptable deviation to standard deviation, $d_{\max}/\sigma$
3	1.38
4	1.54
5	1.65
6	1.73
7	1.80
10	1.96
15	2.13
25	2.33
50	2.57
100	2.81
300	3.14
500	3.29
1000	3.48

Apparatus

The Dial Caliper
The Planimeter

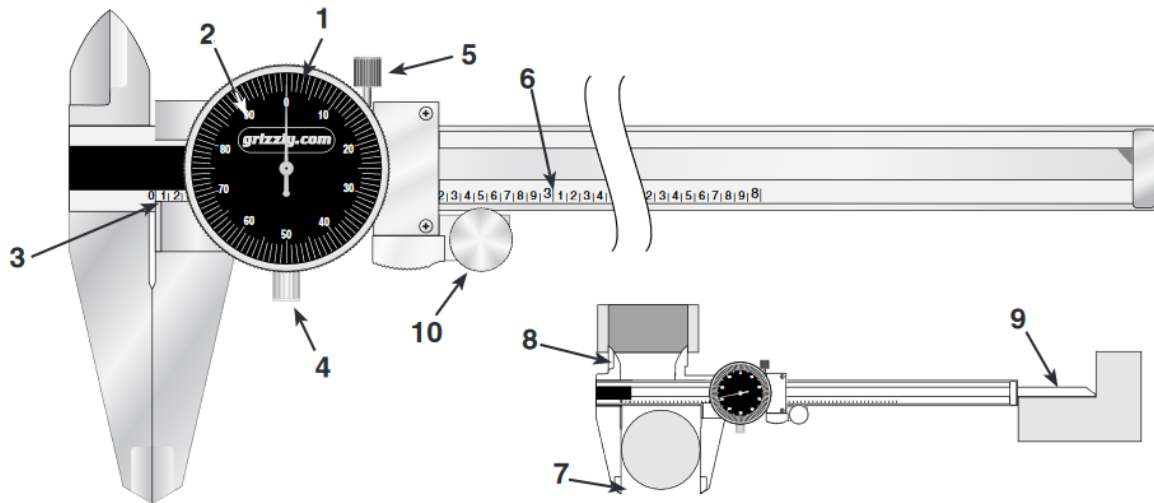


Figure 1 Dial Caliper

1. The distance between the **Lines** equals 0.001" (one thousandths of an inch).
2. The **Dial Numbers** represent 0.010" (ten thousandths of an inch).
3. Each number on the **Revolution Scale** represents one full rotation of the needle and is equal to 0.100" (one hundred thousandths or 1/10 of an inch). The jaw index indicates which number is read.
4. The **Dial Lock** secures the dial after zero is set. Clean the jaw faces of any dirt or dust and close the jaws together. If the hand is not on "0" then you can turn the dial to align it to "0". Once aligned, lock down the bezel with the dial lock.
5. The **Caliper Lock** secures the dial to the body, maintaining a measurement.
6. The **Inch Markers** denote each full inch of measurement.
7. The **External Caliper Jaws** are used for external measurements.
8. The **Internal Jaws** are used for internal measurements.
9. The **Depth Blade** is used to gauge depth.
10. The **Thumbwheel** is used to move the dial assembly along the caliper body.

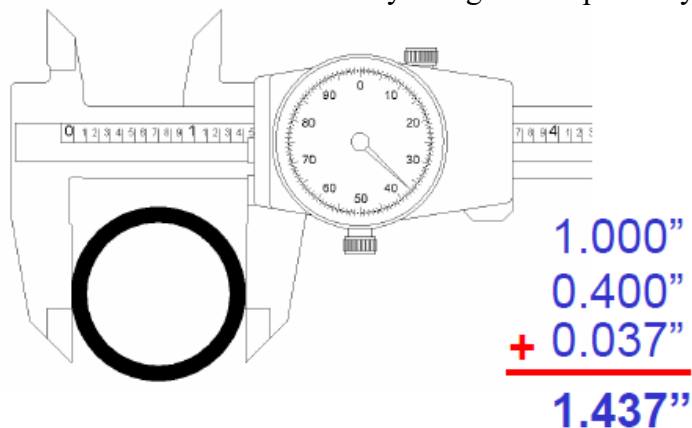


Figure 2 Dial Caliper Reading Example

Reference: Grizzly Industrial Inc.

The Planimeter

The planimeter, shown in Figure 3, is used to measure a closed area by starting at a given point on the perimeter of the area and moving the tracing point along the perimeter until it is back at the original starting point. The area enclosed by the perimeter is recorded on the electronic display of the instrument.

(Provide the Mathematical theory for the Area Computation by a Planimeter)

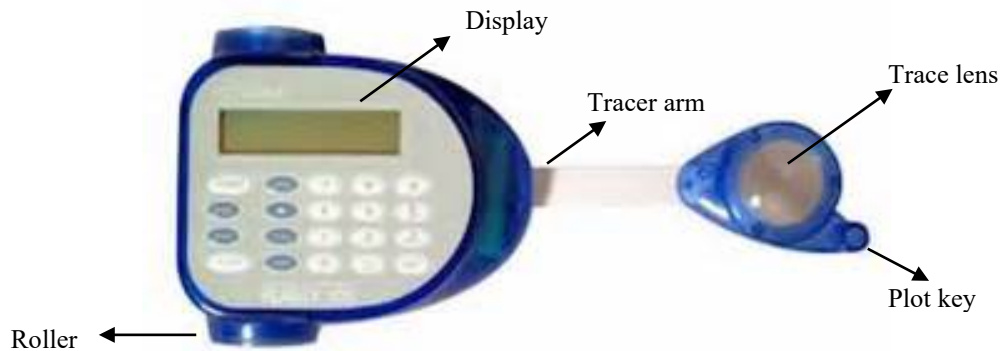


Figure 3 The Planimeter

Procedure

1. Study the information on “**Parts and How to Use a Vernier and Planimeter**” provided above and from several information available on the web.
2. Identify the three wooden blocks numbered 1, 2, and 3.
3. Measure, to 0.01 mm the thickness of each block and record your reading on the personal table provided to you, ensuring that other members in your group do not see your measurement in order to eliminate bias in the measurements.
4. Repeat step 3 for bolts 2 and 3.
5. Use the planimeter to measure the irregular area 1 and the regular area 2
6. Steps 1 through 5 should be repeated by each member in the lab group.
7. When all members in the group complete the measurements, the group leader should collect the table from the members of the group and include the group number on the first page.
8. The group leader should submit the results to the course instructor.
9. The course instructor will collect the results from all of the groups.
10. The course instructor will redistribute a set of the results from a group to the group leader in another group.
11. The group leaders should record the data for the group given to the leader on the master table in the classroom before the end of the class.
12. Each student will make a photographic image of the master tables containing the entire results or the course instructor will scan and post the master results on e-course for all students to access.

Table 1 Raw Experimental Data for Measurements of thickness of Wooden Blocks Using Vernier Caliper

#	Name of Student	Block #1	Block #2	Block #3
Group 1				
1				
2				
3				
4				
5				
6				
Group 2				
7				
8				
9				
10				
11				
12				
Group 3				
13				
14				
15				
16				
17				
18				
Group 4				
19				
20				
21				
22				
23				
24				
Group 5				
25				
26				
27				
28				
29				
30				

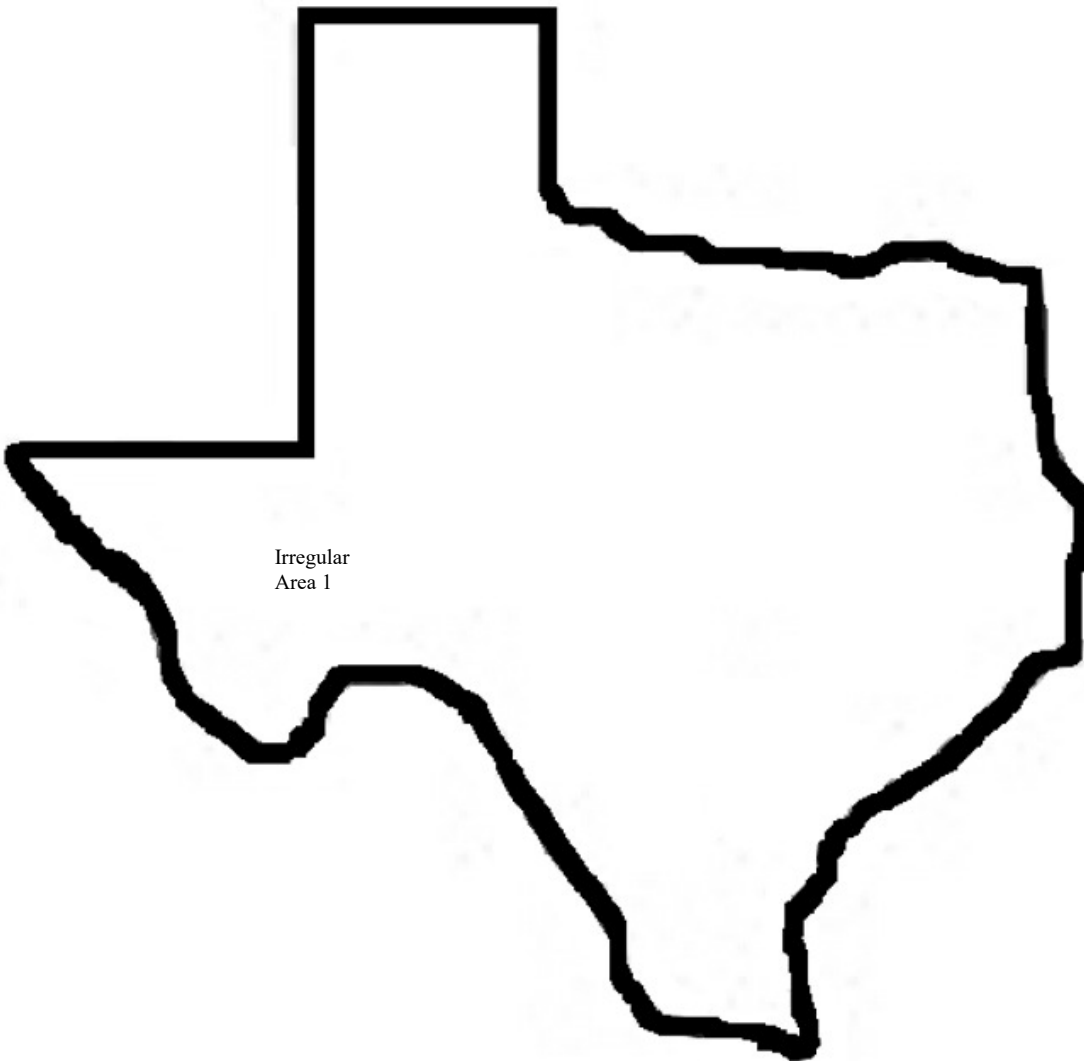
Table 2 Raw Experimental Data for Measurements of Irregular and Regular Areas Using Planimeter

#	Name of Student	Irregular Area #1	Regular Area #2
Group 1			
1			
2			
3			
4			
5			
6			
Group 2			
7			
8			
9			
10			
11			
12			
Group 3			
13			
14			
15			
16			
17			
18			
Group 4			
19			
20			
21			
22			
23			
24			
Group 5			
25			
26			
27			
28			
29			
30			

Areas to be Measured Using the Planimeter

Regular
Area 2

Irregular
Area 1



Analysis and Lab Report.

For this lab you can demonstrate your understanding of the statistical analysis discussed in the theory using Excel. However, you are not allowed to use the built-in functions to compute any of the statistical variables in the theory section.

1. For each set of data for each of the three wooden block and for each set of data for each of the two Area measurements, compute the sum using the sum function of excel
2. Using the number of data in the set and the sum, compute the mean using equation 1.
3. In a column next to each data column, compute the absolute value of the deviation $|d_i|$ each data from the mean using equation 2 in the absolute value sense.
4. Compute the mean deviation for the measurements using equation 3.
5. In a column next to the absolute deviation column, compute the squares of the deviations, i.e. $(x_i - x_m)^2$.
6. Compute the standard deviation using equation 4 or 5, whichever is applicable.
7. In a column next to the column in step 5, compute d_i/σ
8. Determine the acceptable deviation ratio from Table 3.2 based on the number of data.
9. Reject any data with d_i/σ greater than the acceptable ratio in step 8 by highlighting the row for the data and indicating why.
10. Summarize your results for Blocks and the Areas in a table similar to those below in excel.

Table 3 Summary of Computed Results

	Block 1	Block 2	Block 3
Mean, x_m			
Mean Deviation, $ d $			
Standard Deviation, σ			
The Covariance σ/Mean			

Table 4 Summary of Computed Results

	Irregular Area #1	Regular Area #2
Mean, x_m		
Mean Deviation, $ d $		
Standard Deviation, σ		
The Covariance σ/Mean		

11. Make a histogram plot of the mean (Y-axis) versus the Blocks (x-axis) and show error bars at one standard deviation. Make sure the Y-axis starts from zero.
12. Make a histogram plot of the mean (Y-axis) versus the Areas (x-axis) and show error bars at one standard deviation. Make sure the Y-axis starts from zero.
13. Make a histogram plot of the mean deviation (Y-axis) versus the Blocks (x-axis). Do not show error bars. Make sure the Y-axis starts from zero.
14. Make a histogram plot of the mean deviation (Y-axis) versus the Areas (x-axis). Do not show error bars. Make sure the Y-axis starts from zero.
15. Prepare a standard laboratory report following the report template available on e-course.

ABOVE AVERAGE

PRAIRIE VIEW A&M UNIVERSITY



MCEG 3101 MEASUREMENT LABORATORY

Fall 2021 Section P01

LABORATORY REPORT ON

“Statistical Analysis of Data on Linear Measurement Using Dial Calipers and Area Measurement Using Planimeter”

Conducted on
September 21, 2021

Submitted by
Malaika Lee

On
September 28, 2021

To

Dr. Mingli Han
Measurement Laboratory Instructor

MECHANICAL ENGINEERING DEPARTMENT
MEASUREMENT LABORATORY GRADING SHEET
FALL 2021 SECTION P01

Title of Experiment: _____

Name: _____

Date Lab was Performed: _____ Report Due Date: _____

<i>Ability to Conduct Experiments</i>	MAX	Your Score	Comments
Ability to demonstrate general lab safety (by your conduct and observations).	3	3	
Ability to follow the procedure and properly rephrasing the procedure to reflect what you did during the experiment.	7	7	
Ability to demonstrate knowledge of how equipment function, their limitations, and the uncertainty associated with reading the instruments.	5	5	
Ability to collect and record the raw data using appropriate units of measurement and identify the dependent and independent variables in the experiment.	5	5	
Total for Ability to Conduct Experiments	20	20	
Percentage for this Performance Criteria			
<i>Ability to Analyze and Interpret experimental Data in a Formal Report</i>			
Report format (Ability to properly format and present a technical report)	13	11	
Provides appropriate abstracts for the experimental report	5	4	
Ability to analyze the data using appropriate software to generate the required parameters using consistent units	27	27	
Ability to present the data (raw /derived) in tabular and graphical form to meet the objectives and to aid in interpretation.	14	10	
Ability to discuss the raw and derived data/graphs and assess the validity of the results in relation to the underlying theory and expected trends.	14	14	
Ability to draw appropriate and reasonable conclusions in relations to each of the experimental objectives. One conclusion statement for each objective.	7	7	
Total for Ability to Analyze and Interpret experimental Data	80		
TOTAL FOR THIS LAB		93	

Malaika lee
Mechanical Engineering Student
914 Linn Street
Waco, Texas 76704
Cell: 254-717-9889
E-mail: mlee27@pvamu.edu

Dr. Mingli Han
Measurement Laboratory Instructor
Prairie View A&M University
S. R. Collins Engineering Technology Building
Room 311

September 28, 2021, 2020

Dear Dr. Han:

The following pages are a detailed report for lab 2 of MCEG 3011 Measurement Laboratory, "Statistical Analysis of Data on Linear Measurement". This report addresses the use of dial calipers and planimeters for precise measurements as well as the use of statistical analysis of experimental data using the mean, deviation, the mean deviation and the standard deviation. The lab was performed on September 21, 2021 and was submitted on September 28, 2021.

If you have any questions or concerns, please call or email me at any time.

Sincerely,

Malaika lee
Enclosure: Lab Report

ABSTRACT

The purpose of this experiment was to introduce the use of dial calipers and planimeters to assist in the understanding of how to statistically analyze results derived from both tools. Using standard statistical analysis such as, mean, deviation and covariance, the individual can analyze the results of the lab.

During the experiment, the methods that were used consisted of gathering data using dial calipers and planimeters, also analyzing the data using statistical analysis formulas in Microsoft Excel.

From the lab, we can conclude that the data collected from the students from the planimeters were not accurate because many data points did not meet the Chauvenets Criterion.

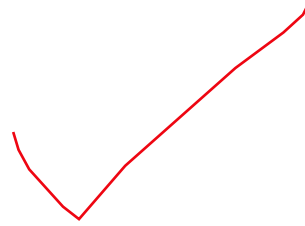
In conclusion the individual should have gained knowledge in the use of dial calipers and planimeters. Also, further practice using statistical analysis.

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CHAPTER 1

ABILITY TO CONDUCT EXPERIMENTS

1.1 Objectives

The objectives of the experiment are to: Learn the use of dial calipers and planimeter for precise measurements. Introduce the use of statistical analysis and Chauvenets Criteria of experimental data using the mean, deviation, the mean deviation and the standard deviation. Plot histograms for a set of experimental data represented by the mean and the standard deviation in the form of $(\bar{x} \pm \sigma)$

1.2 Theory Associated with Experiment

In many situations, it is necessary to conduct several sets of experiments to ensure that the statistical accuracy of the results can be determined. A number of statistical parameters are needed to determine the statistical accuracy of the experimental results. The statistical parameters to be discussed in this section include the mean, the deviation of each data from the mean, the average deviation, and the standard deviation or the root mean square deviation.

Chauvenets Criterion for Rejecting Data

There are instances when an experimenter would have data that that appears to be bad or out of place in comparison to the other data. When this occurs, a decision has to be made as to whether this was caused by some type of experimental blunder and thus should be neglected or that the data was the result of an unknown physical phenomenon. To answer this problem, we need to first calculate the standard deviation of the set of data including the data in question and then analyze the data using the Gaussian or Normal distribution function. The normal distribution function $P(x_m)$ gives the probability that a measurement x , will lie between $x_m + x_1$ and $x_m - x_1$, where x_m is the mean of the set of data. $P(x_1)$ is given by

$$P(x_1) = \int_{x_m - x_1}^{x_m + x_1} \frac{1}{\sigma \sqrt{2\pi}} e^{-(x - x_m)^2 / 2\sigma^2} dx$$

With a change of variables

$$\eta = \frac{x - x_m}{\sigma}$$

$$P(\eta_1) = \int_{-\eta_1 \sigma \sqrt{2\pi}}^{\eta_1} \frac{1}{\sigma \sqrt{2\pi}} e^{-\eta^2 / 2} d\eta$$

With this probability function, we can calculate the probability for a data to fall within 1,2,3,4,5 etc. standard deviations from the mean, as well as the probability for the data to fall outside these deviations from the mean. Table 1 gives these probabilities.

Table 1.1 Standard Deviation Probabilities

Number of Standard Deviations	Probability of Data falling within the number of standard deviations	Probability of data falling outside the number of standard deviations
1	0.68268	0.31732
2	0.95450	0.0455
3	0.9973	0.0027
4	0.9999366	0.0000634

From the table, it is seen that it becomes highly unlikely for data to fall outside of very large standard deviations from the mean. This information can be used to detect data that may be bad. Obviously, the likelihood of a data falling several standard deviations outside the mean is very small and this can be an indicator that the data is bad.

A standard way of using this strategy to detect bad data is through the application of Chauvenet's criterion. Chauvenet's criterion states that a reading may be rejected if the probability of obtaining the deviation from the mean is less than $1/2n$, where n is the number of readings. Using this criterion and the normal probability distribution function, for any number of experimental data, n , the maximum acceptable deviation from the mean can be determined as presented in Table 2.

Table 1.2 Chauvenet's Criterion

Number of Readings	Ratio of maximum acceptable deviation to standard deviation, $ d_{\max} /\sigma$
3	1.38
4	1.54
5	1.65
6	1.73
7	1.80
10	1.96
15	2.13
25	2.33
50	2.57
100	2.81
300	3.14
500	3.29
1000	3.48

1.3 Apparatus and Uncertainty in Reading Instruments

The Dial Caliper

The Planimeter

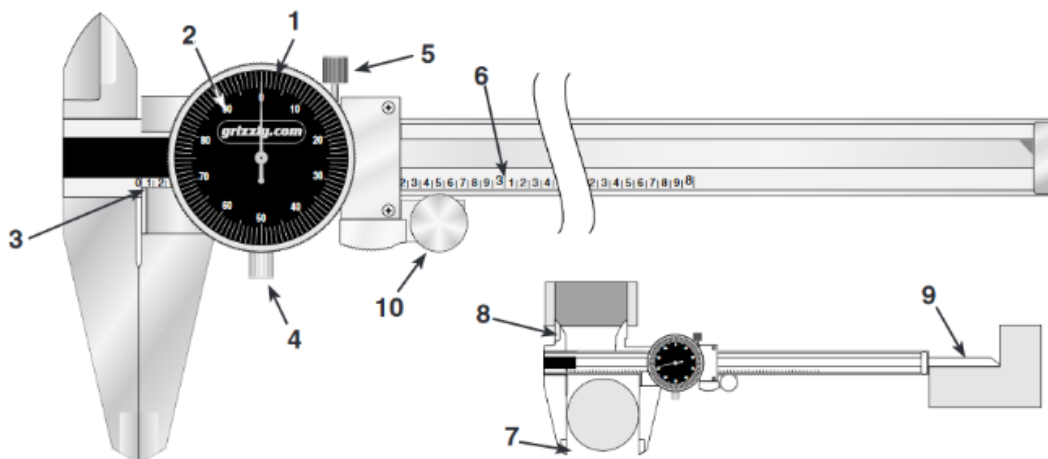


Figure 1.1 Dial Caliper

- 1) The distance between the Lines equals 0.001" (one thousandths of an inch).
- 2) The **Dial Numbers** represent 0.010" (ten thousandths of an inch).
- 3) Each number on the **Revolution Scale** represents one full rotation of the needle and is equal to 0.100" (one hundred thousandths or 1/10 of an inch). The jaw index indicates which number is read.
- 4) The **Dial Lock** secures the dial after zero is set. Clean the jaw faces of any dirt or dust and close the jaws together. If the hand is not on "0" then you can turn the dial to align it to "0". Once aligned, lock down the bezel with the dial lock.
- 5) The **Caliper Lock** secures the dial to the body, maintaining a measurement
- 6) The **Inch Markers** denote each full inch of measurement.
- 7) The **External Caliper Jaws** are used for external measurements
- 8) The **Internal Jaws** are used for internal measurements
- 9) The **Depth Blade** is used to gauge depth.
- 10) The **Thumbwheel** is used to move the dial assembly along the caliper body

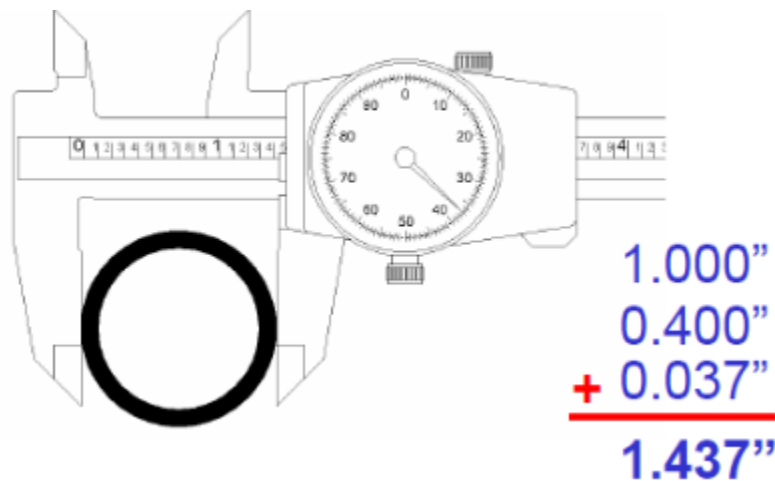


Figure 1.2 Dial Caliper Reading Example

The Planimeter

The planimeter, shown in Figure 3, is used to measure a closed area by starting at a given point on the perimeter of the area and moving the tracing point along the perimeter until it is back at the original starting point. The area enclosed by the perimeter is recorded on the electronic display of the instrument.



Figure 1.3 The Planimeter

1.4 Experimental Safety

I did not observe any safety concerns that should be addressed for the experiment.

1.5 Experimental Procedure

- 1) Study the information on “Parts and How to Use a Vernier and Planimeter” provided above and from several information available on the web
- 2) Identify the three wooden blocks numbered 1, 2, and 3.
- 3) Measure, to 0.01 mm the thickness of each block and record your reading on the personal table provided to you, ensuring that other members in your group do not see your measurement in order to eliminate bias in the measurements.
- 4) Repeat step 3 for block 2 and 3
- 5) Use the planimeter to measure the irregular area 1 and the regular area 2
- 6) Steps 1 through 5 should be repeated by each member in the lab group.
- 7) When all members in the group complete the measurements, the group leader should collect the table from the members of the group and include the group number on the first page.
- 8) The group leader should submit the results to the course instructor.
- 9) The course instructor will collect the results from all of the groups.
- 10) The course instructor will redistribute a set of the results from a group to the group leader in another group.
- 11) The group leaders should record the data for the group given to the leader on the master table in the classroom before the end of the class.
- 12) Each student will make a photographic image of the master tables containing the entire results or the course instructor will scan and post the master results on e-course for all students to access.

1.6 Presentation of Raw Experimental Data

Block 1 (inch)	Block 2 (inch)	Block 3 (inch)	Irregular Area (inch ²)	Regular Area (inch ²)
0.9670	0.9340	0.9530	11.6360	0.8500
0.9450	0.9440	0.9470	12.3320	0.8050
0.9430	0.9310	0.9530	12.2260	0.8640
0.9400	0.9370	0.9430	14.5050	1.0525
0.9400	0.9370	0.9430	14.5050	1.0530
0.9380	0.9320	0.9470	15.3660	1.0600
1.0500	0.9230	1.0390	12.3260	0.8460
0.9500	0.9300	0.9600	12.2500	0.8450
0.9450	0.9320	0.9500	12.1100	0.8340
1.0450	0.9250	0.9460	12.3020	0.8360
0.9410	0.9260	0.9460	14.7210	0.9734
0.9430	0.9260	0.9500	16.1517	1.0357
0.9410	0.9290	0.9530	10.3519	1.0435
0.9400	0.9320	0.9420	12.1400	0.8310
0.9470	0.9350	0.9480	12.2180	0.8260
0.9420	0.9370	0.9590	12.2800	0.8280
0.9470	0.9320	0.9440	13.5800	1.0680
0.9520	0.9320	0.9440	14.6325	1.0583
0.9460	0.9300	0.9570	12.1425	0.8206
0.9460	0.9420	0.9650	12.1425	0.8206
0.9440	0.9270	0.9600	12.1425	0.8206
0.9380	0.9300	0.9450	12.1425	1.0802
0.946	0.942	0.965	12.1425	0.8206
0.944	0.927	0.96	12.1425	0.8206
0.938	0.83	0.945	12.1425	1.0802

Table 1.3 Raw Data

CHAPTER 2

ABILITY TO ANALYZE EXPERIMENTAL DATA

2.1 Detailed Computer Analysis of All Data **Table 2.1 Detailed calibration for the 3 blocks.**

Name	Block 1 (inch)	d	d ²	d /σ	Block 2 (inch)	d	d ²	d /σ	Block 3 (inch)	d	d ²	d /σ
	0.9670	0.0143	0.0002	0.5002	0.9340	0.0059	0.0000350	0.2858	0.9530	0.0016	0.0000	0.0839
	0.9450	0.0077	0.0001	0.2704	0.9440	0.0159	0.0002534	0.7686	0.9470	0.0076	0.0001	0.4065
	0.9430	0.0097	0.0001	0.3405	0.9310	0.0029	0.0000085	0.1410	0.9530	0.0016	0.0000	0.0839
	0.9400	0.0127	0.0002	0.4455	0.9370	0.0089	0.0000796	0.4306	0.9430	0.0116	0.0001	0.6216
	0.9400	0.0127	0.0002	0.4455	0.9370	0.0089	0.0000796	0.4306	0.9430	0.0116	0.0001	0.6216
	0.9380	0.0147	0.0002	0.5156	0.9320	0.0039	0.0000154	0.1893	0.9470	0.0076	0.0001	0.4065
	1.0500	0.0973	0.0095	3.4074	0.9230	0.0051	0.0000258	0.2453	1.0390	0.0844	0.0071	4.5405
	0.9500	0.0027	0.0000	0.0953	0.9300	0.0019	0.0000037	0.0927	0.9600	0.0054	0.0000	0.2925
	0.9450	0.0077	0.0001	0.2704	0.9320	0.0039	0.0000154	0.1893	0.9500	0.0046	0.0000	0.2452
	1.0450	0.0923	0.0085	3.2323	0.9250	0.0031	0.0000095	0.1487	0.9460	0.0086	0.0001	0.4603
	0.9410	0.0117	0.0001	0.4105	0.9260	0.0021	0.0000043	0.1004	0.9460	0.0086	0.0001	0.4603
	0.9430	0.0097	0.0001	0.3405	0.9260	0.0021	0.0000043	0.1004	0.9500	0.0046	0.0000	0.2452
	0.9410	0.0117	0.0001	0.4105	0.9290	0.0009	0.0000008	0.0444	0.9530	0.0016	0.0000	0.0839
	0.9400	0.0127	0.0002	0.4455	0.9320	0.0039	0.0000154	0.1893	0.9420	0.0126	0.0002	0.6754
	0.9470	0.0057	0.0000	0.2004	0.9350	0.0069	0.0000479	0.3341	0.9480	0.0066	0.0000	0.3527
	0.9420	0.0107	0.0001	0.3755	0.9370	0.0089	0.0000796	0.4306	0.9590	0.0044	0.0000	0.2387
	0.9470	0.0057	0.0000	0.2004	0.9320	0.0039	0.0000154	0.1893	0.9440	0.0106	0.0001	0.5678
	0.9520	0.0007	0.0000	0.0252	0.9320	0.0039	0.0000154	0.1893	0.9440	0.0106	0.0001	0.5678
	0.9460	0.0067	0.0000	0.2354	0.9300	0.0019	0.0000037	0.0927	0.9570	0.0024	0.0000	0.1312
	0.9460	0.0067	0.0000	0.2354	0.9420	0.0139	0.0001938	0.6720	0.9650	0.0104	0.0001	0.5614
	0.9440	0.0087	0.0001	0.3054	0.9270	0.0011	0.0000012	0.0521	0.9600	0.0054	0.0000	0.2925
	0.9380	0.0147	0.0002	0.5156	0.9300	0.0019	0.0000037	0.0927	0.9450	0.0096	0.0001	0.5141
	0.946	0.0067	0.0000	0.2354	0.942	0.0139	0.0001938	0.6720	0.965	0.0104	0.0001	0.5614
	0.944	0.0087	0.0001	0.3054	0.927	0.0011	0.0000012	0.0521	0.96	0.0054	0.0000	0.2925
	0.938	0.0147	0.0002	0.5156	0.83	0.0981	0.0096197	4.7352	0.945	0.0096	0.0001	0.5141
Sum	23.8180	0.4077	0.0204		23.2020	0.2251	0.0107		23.8640	0.2570	0.0086	
N	25	25	25		25	25	25		25	25	25	
Mean	0.95272	0.0163072	0.000815082		0.92808	0.0090048	0.000429034		0.95456	0.0102816	0.000345846	
STD			0.028549634				0.020713126				0.018596946	
COV			0.029966448				0.022318255				0.019482218	

Figure 2.1 Computer Analysis of Dial Caliper

Irregular Area (inch ²)	d	d ²	d /σ	Regular Area (inch ²)	d	d ²	d /σ
11.6360	1.1892	1.4143	0.8914	0.8500	0.0689	0.0047	0.6290
12.3320	0.4932	0.2433	0.3697	0.8050	0.1139	0.0130	1.0397
12.2260	0.5992	0.3591	0.4492	0.8640	0.0549	0.0030	0.5012
14.5050	1.6798	2.8216	1.2592	1.0525	0.1336	0.0178	1.2193
14.5050	1.6798	2.8216	1.2592	1.0530	0.1341	0.0180	1.2238
15.3660	2.5408	6.4555	1.9046	1.0600	0.1411	0.0199	1.2877
12.3260	0.4992	0.2492	0.3742	0.8460	0.0729	0.0053	0.6655
12.2500	0.5752	0.3309	0.4312	0.8450	0.0739	0.0055	0.6746
12.1100	0.7152	0.5115	0.5361	0.8340	0.0849	0.0072	0.7750
12.3020	0.5232	0.2738	0.3922	0.8360	0.0829	0.0069	0.7568
14.7210	1.8958	3.5940	1.4211	0.9734	0.0545	0.0030	0.4973
16.1517	3.3265	11.0654	2.4935	1.0357	0.1168	0.0136	1.0659
10.3519	2.4733	6.1173	1.8540	1.0435	0.1246	0.0155	1.1371
12.1400	0.6852	0.4695	0.5136	0.8310	0.0879	0.0077	0.8024
12.2180	0.6072	0.3687	0.4552	0.8260	0.0929	0.0086	0.8480
12.2800	0.5452	0.2973	0.4087	0.8280	0.0909	0.0083	0.8298
13.5800	0.7548	0.5697	0.5658	1.0680	0.1491	0.0222	1.3608
14.6325	1.8073	3.2662	1.3547	1.0583	0.1394	0.0194	1.2722
12.1425	0.6827	0.4661	0.5118	0.8206	0.0983	0.0097	0.8973
12.1425	0.6827	0.4661	0.5118	0.8206	0.0983	0.0097	0.8973
12.1425	0.6827	0.4661	0.5118	0.8206	0.0983	0.0097	0.8973
12.1425	0.6827	0.4661	0.5118	1.0802	0.1613	0.0260	1.4721
12.1425	0.6827	0.4661	0.5118	0.8206	0.0983	0.0097	0.8973
12.1425	0.6827	0.4661	0.5118	0.8206	0.0983	0.0097	0.8973
12.1425	0.6827	0.4661	0.5118	1.0802	0.1613	0.0260	1.4721
320.6306	27.3693	44.4918		22.9728	2.6314	0.3001	
25	25	25		25	25	25	
12.825224	1.09477056	1.77967309		0.918912	0.1052544	0.012004069	
		1.334043886				0.109563083	
		0.1040172				0.119231311	

Figure 2.2 Computer Analysis of Planimeter

2.2 Presentation of Tables of Derived Results

	Block 1	Block 2	Block 3
Mean, X_m	0.953	0.92808	0.955
Mean Deviation, $ d $	0.016	0.00900	0.010
Standard Deviation, σ	0.029	0.02071	0.019
The Covariance, σ/x_m	0.030	0.02232	0.019

Table 2.2 Derived Results

Table 2.2 summarizes the statistical data collected during the experiment. The mean, mean deviation, standard deviation, and covariance are shown for the three blocks.

	Irregular Area #1	Regular Area #2
Mean, X_m	12.825	0.919
Mean Deviation, $ d $	1.095	0.105
Standard Deviation, σ	1.334	0.110
The Covariance, σ/x_m	0.104	0.119

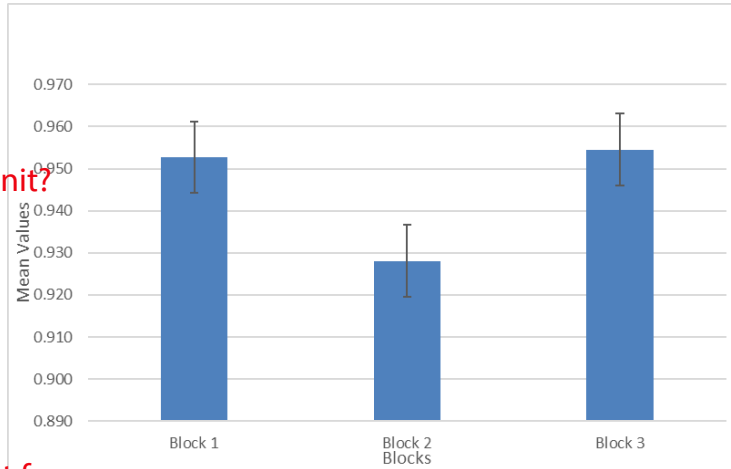
Table 2.3 More Derived Results

Table 2.3 summarizes the statistical data collected during the experiment. The mean, mean deviation, and covariance are shown for the two areas.

CHAPTER 3

ABILITY TO INTERPRET EXPERIMENTAL DATA

3.1 Presentation of Graphs/Figures and Interpretation of Results Presented by each Graph/Figure



As graph 3.1 shows, the mean values for blocks one and three are similar; however the mean values for block two are significantly smaller than the others.

start from zero

Figure 3.1 Mean Values vs. Blocks

As Graph 3.2 shows, the mean values collected for each area varied greatly. Area two was considerably smaller compared to area one.

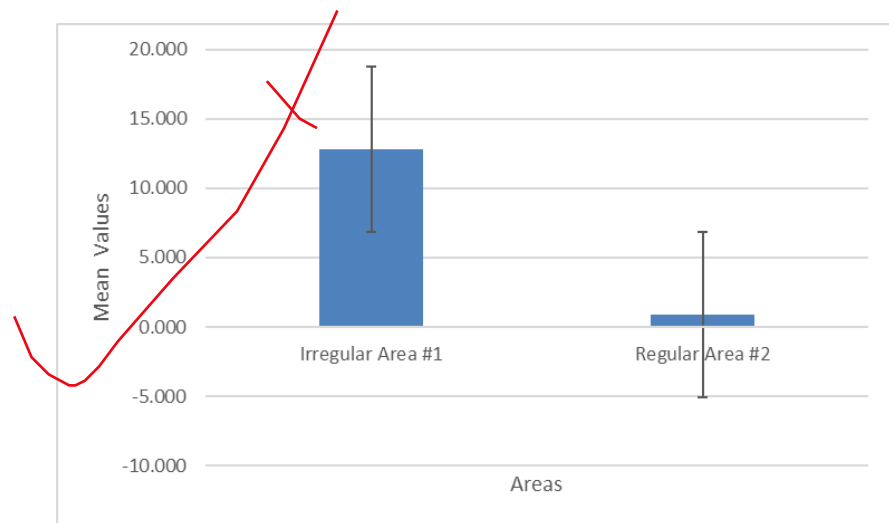


Figure 3.2 Mean Values vs. Areas

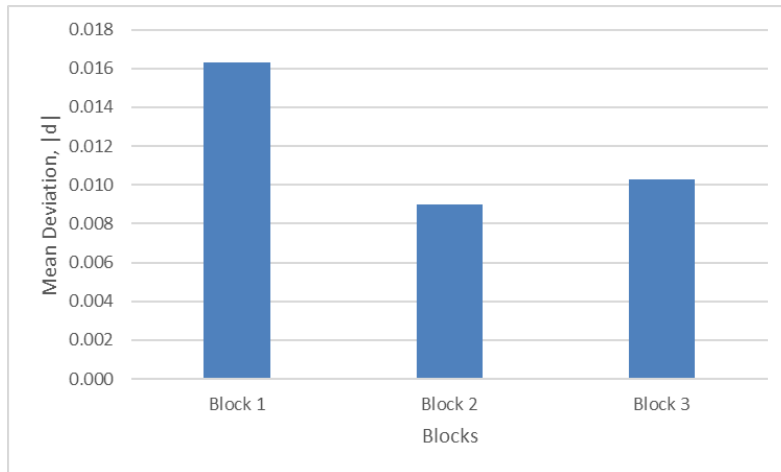


Figure 3.3 Mean Deviations vs. Blocks

As Graph 3.3 shows, the mean deviation of each block. The data collected for block one had the highest mean deviation, so the data points varied greater than the collection points for the other blocks.

As Graph 3.3 shows, the mean deviations for both areas. The mean deviation of the first area was considerably larger than the second area

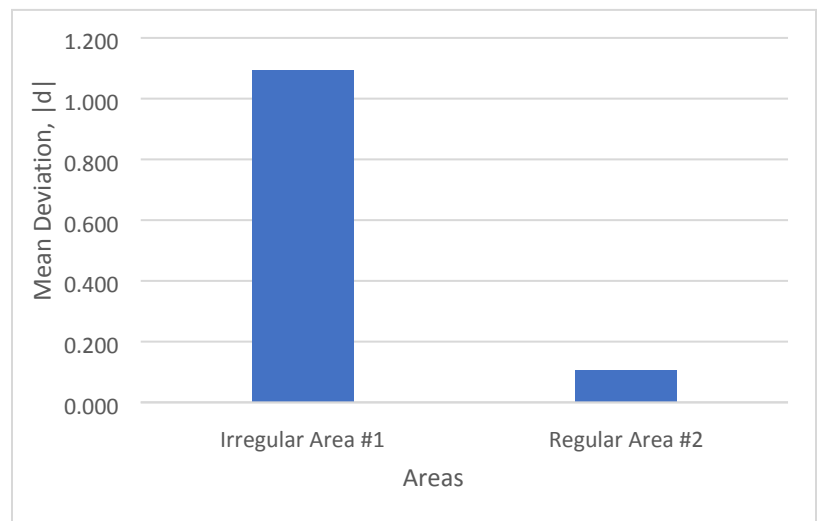


Figure 3.4 Mean Deviations vs. Areas

3.2 Conclusions Based on each Objective and the Results

In conclusion, this lab introduced the use of dial calipers and planimeters as measurement tools. From the experiment, it can be concluded that the area one was larger than area two by analyzing the mean values that were collected. We can also conclude that the blocks one and three were similar in size due to the mean values collected.

3.3 Recommendations

Based on the Chauvenet's Criterion, many data points collected for both areas could be rejected. Therefore, I recommend that the students should receive more practice with the tools to provide more precise measurements.

AVERAGE

**MECHANICAL ENGINEERING DEPARTMENT
PRAIRIE VIEW A&M UNIVERSITY**



MCEG 3101 MEASUREMENT LABORATORY

Fall 2021 Section P01

LABORATORY REPORT ON

**“Statistical Analysis of Data on Linear Measurement Using Dial
Calipers and Area Measurement Using Planimeter”**

**Conducted on
September 21, 2021**

**Submitted by
Heba Afzal**

**On
September 27, 2021**

To

**Dr. Mingli Han
*Measurement Laboratory Instructor***

**MECHANICAL ENGINEERING DEPARTMENT
MEASUREMENT LABORATORY GRADING SHEET**

FALL 2021 SECTION P01

Experiment Title: "Statistical Analysis of Data on Linear Measurement Using Dial Calipers and
Area Measurement Using Planimeter"

Name: Heba Afzal Date Lab was Performed: 9/21/21 Report Due Date: 9/27/21

<i>Ability to Conduct Experiments</i>	MAX	Your Score	Comments
Ability to demonstrate general lab safety (by your conduct and observations).	3	3	
Ability to follow the procedure and properly rephrasing the procedure to reflect what you did during the experiment.	7	7	
Ability to demonstrate knowledge of how equipment function, their limitations, and the uncertainty associated with reading the instruments.	5	5	
Ability to collect and record the raw data using appropriate units of measurement and identify the dependent and independent variables in the experiment.	5	5	
Total for Ability to Conduct Experiments	20	20	
Percentage for this Performance Criteria			
<i>Ability to Analyze and Interpret experimental Data in a Formal Report</i>			
Report format (Ability to properly format and present a technical report)	13	11	
Provides appropriate abstracts for the experimental report	5	4	
Ability to analyze the data using appropriate software to generate the required parameters using consistent units	27	12	
Ability to present the data (raw /derived) in tabular and graphical form to meet the objectives and to aid in interpretation.	14	10	
Ability to discuss the raw and derived data/graphs and assess the validity of the results in relation to the underlying theory and expected trends.	14	14	
Ability to draw appropriate and reasonable conclusions in relations to each of the experimental objectives. One conclusion statement for each objective.	7	7	
Total for Ability to Analyze and Interpret experimental Data	80		
TOTAL FOR THIS LAB		78	

Heba Afzal
Mechanical Engineering Student
9522 Bending Willow Ln
Houston Tx 77064
Cell: 832-805-5485
E-mail: hafzal@student.pvamu.edu

Dr. Mingli Han
Measurement Laboratory Instructor
Prairie View A&M University
S. R. Collins Engineering Technology Building
Room 311

September 27, 2021

Dear Dr. Han:

The following pages are a detailed report for lab 2 of MCEG 3101 Measurement Laboratory, “Statistical Analysis of Data on Linear Measurement Using Dial Calipers and Area Measurement Using Planimeter”. This report addresses the use of dial calipers and planimeters for precise measurements as well as the use of statistical analysis of experimental data using the mean, deviation, the mean deviation, the standard deviation, and Chauvenets Criterion for Rejecting Data. The lab was performed on September 21, 2021 and was submitted on September 27, 2021.

If you have any questions or concerns, please call or email me at any time.

Sincerely,

Heba Afzal
Enclosure: Lab Report

Abstract

1. Purpose of experiment: The purpose of this experiment is to learn how to use a caliper to measure the width of a wooden block and to learn how to use a planimeter to measure the area of both regular and irregular shapes. The data collected was used to run standard statistical analysis
2. Brief description of method used: We used a caliper to measure the thickness of wooden blocks and we used a planimeter to calculate the area of 2d shaped.
3. Significant results of the test: It was determined that the wooden blocks had a very similar mean and the same mean deviation. For the area calculated by the planimeter it was determined that the regular area was much smaller than the irregular area, therefore both the mean deviation and the mean varied greatly.
4. The major conclusions drawn from the results:

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CHAPTER 1 ABILITY TO CONDUCT EXPERIMENTS

Statistical Analysis of Data on Linear Measurement Using Dial Calipers and Area Measurement Using Planimeter

1.1 Objectives:

The objectives of the experiment are to:

1. Learn the use of dial calipers and planimeter for precise measurements.
2. Introduce the use of statistical analysis and Chauvenets Criteria of experimental data using the mean, deviation, the mean deviation and the standard deviation.
3. Plot histograms for a set of experimental data represented by the mean and the standard deviation in the form of $(x_m \pm \sigma)$

1.2 Theory

Statistical Analysis of Experimental Data

In many situations, it is necessary to conduct several set of experiments to ensure that the statistical accuracy of the results can be determined. A number of statistical parameters are needed to determine the statistical accuracy of the experimental results. The statistical parameters to be discussed in this section include the mean, the deviation of each data from the mean, the average deviation, and the standard deviation or the root mean square deviation.

The Mean: The mean x_m , of a set of n data in which each data is represented by x_i ($i=1$ to n) is given by

$$x_m = \frac{1}{n} \sum_{i=1}^n x_i \quad (1)$$

The Deviation: The deviation d_i of a set of n data in which each data is represented by x_i ($i=1$ to n) is given by

$$d_i = x_i - x_m \quad (2)$$

Note that the average of the deviations of all the data is zero since the sum of the deviation is zero.

The Mean Deviation: The average of the absolute values of the deviations is however not zero, and is given by

$$\bar{d} = \frac{1}{n} \sum |x_i - x_m| \quad (3) \text{The Standard}$$

Deviation: The standard deviation is also known as the root mean square deviation. It is one of the most important statistical parameters that are used to ascertain the accuracy as well as the confidence one will have in the value of the measured data. The standard deviation for a very large set of data is given by

$$\sigma = \left[\frac{1}{n} \sum_{i=1}^n (x_i - x_m)^2 \right]^{1/2} \quad (4)$$

When the number of data is not large (less than 20 for example), the sample standard deviation is given by

$$\sigma = \left[\frac{\sum (x_i - x_m)^2}{n-1} \right]^{1/2} \quad (5)$$

The Covariance: COV=Standard Deviation/Mean

Chauvenets Criterion for Rejecting Data

There are instances when an experimenter would have data that that appears to be bad or out of place in comparison to the other data. When this occurs, a decision has to be made as to whether this was caused by some type of experimental blunder and thus should be neglected or that the data was the result of an unknown physical phenomenon. To answer this problem, we need to first calculate the standard deviation of the set of data including the data in question and then analyze the data using the Gaussian or Normal distribution function. The normal distribution function $P(x_m)$ gives the probability that a measurement x , will lie between $x_m + x_1$ and $x_m - x_1$, where x_m is the mean of the set of data. $P(x_1)$ is given by

$$P(x_1) = \int_{x_m - x_1}^{x_m + x_1} \frac{1}{\sigma \sqrt{2\pi}} e^{-(x - x_m)^2 / 2\sigma^2} dx \quad (6)$$

With a change of variables $\eta = \frac{x - x_m}{\sigma}$

$$P(\eta_1) = \int_{-\eta_1}^{\eta_1} \frac{1}{\sigma \sqrt{2\pi}} e^{-\eta^2 / 2} d\eta \quad (7)$$

With this probability function, we can calculate the probability for a data to fall within 1,2,3,4,5 etc. standard deviations from the mean, as well as the probability for the data to fall outside these deviations from the mean. Table 1 gives these probabilities.

Table 1.1 Probability of a Data Falling Within Specified Number of Standard Deviations

Number of Standard Deviations	Probability of Data falling within the number of standard deviations	Probability of data falling outside the number of standard deviations
1	0.68268	0.31732
2	0.95450	0.0455
3	0.9973	0.0027
4	0.9999366	0.0000634

From the table, it is seen that it becomes highly unlikely for data to fall outside of very large standard deviations from the mean. This information can be used to detect data that may be bad. Obviously, the likelihood of a data falling several standard deviations outside the mean is very small and this can be an indicator that the data is bad.

A standard way of using this strategy to detect bad data is through the application of Chauvenet's criterion. Chauvenet's criterion states that a reading may be rejected if the probability of obtaining the particular deviation from the mean is less than $1/2n$, where n is the number of readings. Using this criterion and the normal probability distribution function, for any number of experimental data, n , the maximum acceptable deviation from the mean can be determined as presented in Table 2.

Table 1.2 Maximum Acceptable Deviation Ratio as a Function of the Number of Readings

Number of Readings	Ratio of maximum acceptable deviation to standard deviation, $ d_{\max} /\sigma$
3	1.38
4	1.54
5	1.65
6	1.73
7	1.80
10	1.96
15	2.13
25	2.33
50	2.57
100	2.81
300	3.14
500	3.29
1000	3.48

1.3 Apparatus

The Dial Caliper

The Planimeter

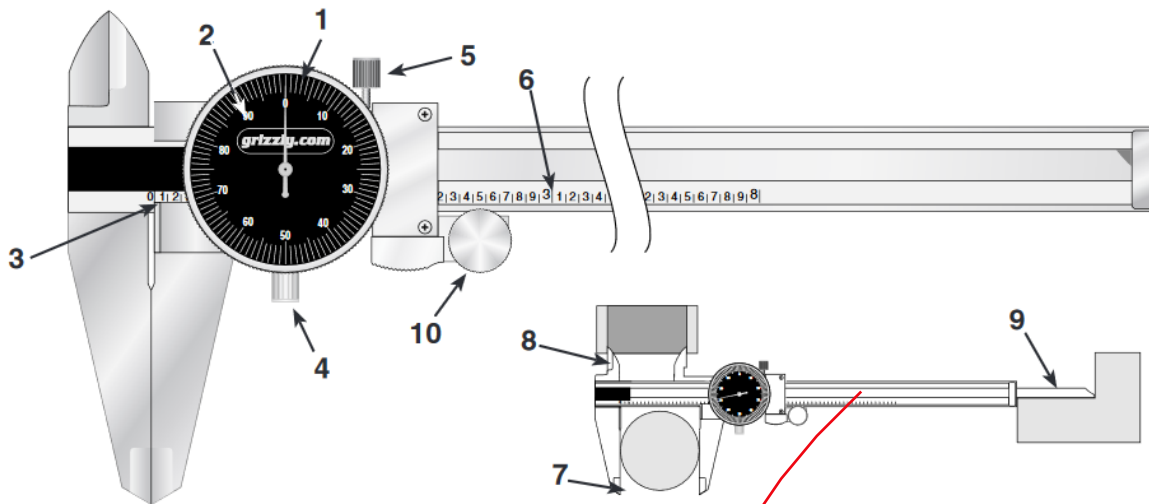


Figure 1.1 Dial Caliper

1. The distance between the **Lines** equals 0.001" (one thousandths of an inch).
2. The **Dial Numbers** represent 0.010" (ten thousandths of an inch).
3. Each number on the **Revolution Scale** represents one full rotation of the needle and is equal to 0.100" (one hundred thousandths or 1/10 of an inch). The jaw index indicates which number is read.
4. The **Dial Lock** secures the dial after zero is set. Clean the jaw faces of any dirt or dust and close the jaws together. If the hand is not on "0" then you can turn the dial to align it to "0". Once aligned, lock down the bezel with the dial lock.

5. The **Caliper Lock** secures the dial to the body, maintaining a measurement.
6. The **Inch Markers** denote each full inch of measurement.
7. The **External Caliper Jaws** are used for external measurements.
8. The **Internal Jaws** are used for internal measurements.
9. The **Depth Blade** is used to gauge depth.
10. The **Thumbwheel** is used to move the dial assembly along the caliper body.

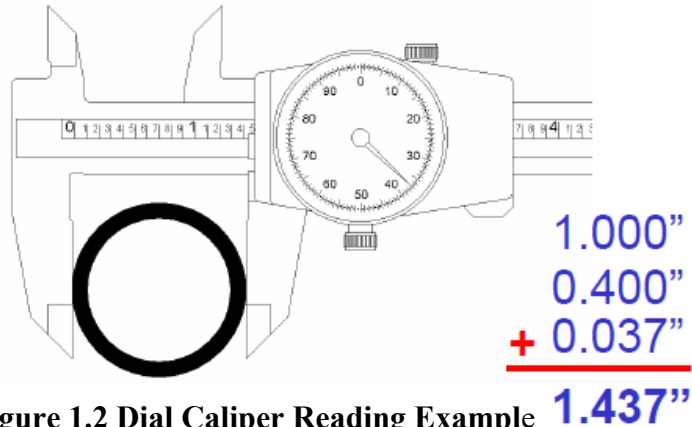


Figure 1.2 Dial Caliper Reading Example
Reference: Grizzly Industrial Inc.

The Planimeter

The planimeter, shown in Figure 3, is used to measure a closed area by starting at a given point on the perimeter of the area and moving the tracing point along the perimeter until it is back at the original starting point. The area enclosed by the perimeter is recorded on the electronic display of the instrument.

Planimeter Theory

When you turn the Planimeter on and press the plot key which indicates the start of the segment and begin moving it the wheel rolls along the perimeter of the 2D shape the motion of the segment and the vector direction are recorded. What determines the area is this and the number of rotation the wheel undergoes from point A around the perimeter and back to point A.

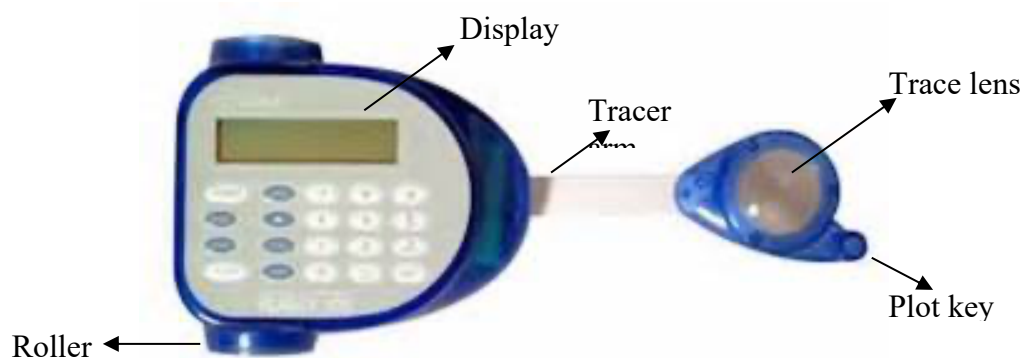


Figure 1.3 The Planimeter

1.4 Experimental Safety

I observed no safety concerns

1.5 Experimental Procedure

Dial Caliper: To use the Dial Caliper we first made sure that it was at the zero position when it was completely closed. We then located each of the 3 blocks and measured them. We loosened the caliper lock and placed the external caliper jaws around the thickness of wooden block, tightened the caliper lock and wrote down the results. We loosened the lock removed the block and did the same with the rest of the blocks.

Planimeter: To use the planimeter we first turned it on, we swung the tracer arm up and down to initialize it. We then identified both the regular and irregular shape we were calculating the area of. Once we identified the shape we hovered the trace lens on the top left corner and centered the red dot on the perimeter line. We pressed the plot key and moved around the perimeter of the shape in a clockwise motion so our area would be positive. When we reached our starting position the measurement was complete and we recorded the value.

1.6 Presentation of raw experimental data

Table 1.6

Block 1 (inch)	Block 2(inch)	Block 3 (inch)	Irregular Area (inch ²)	Regular Area (inch ²)
0.9670	0.9340	0.9530	11.6360	0.8500
0.9450	0.9440	0.9470	12.3320	0.8050
0.9430	0.9310	0.9530	12.2260	0.8640
0.9400	0.9370	0.9430	14.5050	1.0525
0.9400	0.9370	0.9430	14.5050	1.0530
0.9380	0.9320	0.9470	15.3660	1.0600
1.0500	0.9230	1.0390	12.3260	0.8460
0.9500	0.9300	0.9600	12.2500	0.8450
0.9450	0.9320	0.9500	12.1100	0.8340
1.0450	0.9250	0.9460	12.3020	0.8360
0.9410	0.9260	0.9460	14.7210	0.9734
0.9430	0.9260	0.9500	16.1517	1.0357
0.9410	0.9290	0.9530	10.3519	1.0435
0.9400	0.9320	0.9420	12.1400	0.8310
0.9470	0.9350	0.9480	12.2180	0.8260
0.9420	0.9370	0.9590	12.2800	0.8280
0.9470	0.9320	0.9440	13.5800	1.0680
0.9520	0.9320	0.9440	14.6325	1.0583
0.9460	0.9300	0.9570	12.1425	0.8206
0.9460	0.9420	0.9650	12.1425	0.8206
0.9440	0.9270	0.9600	12.1425	0.8206
0.9380	0.9300	0.9450	12.1425	1.0802
0.946	0.942	0.965	12.1425	0.8206
0.944	0.927	0.96	12.1425	0.8206
0.938	0.83	0.945	12.1425	1.0802

CHAPTER 2 ABILITY TO ANALYZE EXPERIMENTAL DATA

2.1 DETAILED COMPUTER ANALYSIS OF DATA

Table 2.1.1

Block 1 (inch)	d	d ²
0.9670	1.014988664	1.030202
0.9450	0.991896885	0.9838594
0.9430	0.989797632	0.9796994
0.9400	0.986648753	0.9734758
0.9400	0.986648753	0.9734758
0.9380	0.9845495	0.9693377
1.0500	1.10210765	1.2146413
0.9500	0.997145016	0.9942982
0.9450	0.991896885	0.9838594
1.0450	1.096859518	1.2031008
0.9410	0.987698379	0.9755481
0.9430	0.989797632	0.9796994
0.9410	0.987698379	0.9755481
0.9400	0.986648753	0.9734758
0.9470	0.993996137	0.9880283
0.9420	0.988748006	0.9776226
0.9470	0.993996137	0.9880283
0.9520	0.999244269	0.9984891
0.9460	0.992946511	0.9859428
0.9460	0.992946511	0.9859428
0.9440	0.990847258	0.9817783
0.9380	0.9845495	0.9693377
0.946	0.992946511	0.9859428
0.944	0.990847258	0.9817783
0.938	0.9845495	0.9693377
N	25	25
Sum	23.8180	25.0000
Mean	0.95272	1.000898
Mean Deviation		1
Std		1.0004489
Covariance		1.0500975

missing |d|/sigma column

Table 2.1.2

Block 2(inch)	 d 	d^2
0.9340	1.006379	1.012798209
0.9440	1.017154	1.034601636
0.9310	1.003146	1.00630246
0.9370	1.009611	1.019314857
0.9370	1.009611	1.019314857
0.9320	1.004224	1.008465388
0.9230	0.994526	0.989082629
0.9300	1.002069	1.004141854
0.9320	1.004224	1.008465388
0.9250	0.996681	0.993373655
0.9260	0.997759	0.995522651
0.9260	0.997759	0.995522651
0.9290	1.000991	1.00198357
0.9320	1.004224	1.008465388
0.9350	1.007456	1.014968103
0.9370	1.009611	1.019314857
0.9320	1.004224	1.008465388
0.9320	1.004224	1.008465388
0.9300	1.002069	1.004141854
0.9420	1.014999	1.030222375
0.9270	0.998836	0.997673969
0.9300	1.002069	1.004141854
0.942	1.014999	1.030222375
0.927	0.998836	0.997673969
0.83	0.894319	0.799807288
N	25	25
Sum	23.2020	25.0000
Mean	0.92808	1.000498105
Mean Deviation		1
Std		1.000249021
Covariance		1.077761638

Table 2.1.3

Block 3 (inch)	 d 	d^2
0.9530	0.998365739	0.996734
0.9470	0.992080121	0.984223
0.9530	0.998365739	0.996734
0.9430	0.987889708	0.975926
0.9430	0.987889708	0.975926
0.9470	0.992080121	0.984223
1.0390	1.088459604	1.184744
0.9600	1.005698961	1.01143
0.9500	0.99522293	0.990469
0.9460	0.991032518	0.982145
0.9460	0.991032518	0.982145
0.9500	0.99522293	0.990469
0.9530	0.998365739	0.996734
0.9420	0.986842105	0.973857
0.9480	0.993127724	0.986303
0.9590	1.004651358	1.009324
0.9440	0.988937311	0.977997
0.9440	0.988937311	0.977997
0.9570	1.002556152	1.005119
0.9650	1.010936976	1.021994
0.9600	1.005698961	1.01143
0.9450	0.989984915	0.98007
0.965	1.010936976	1.021994
0.96	1.005698961	1.01143
0.945	0.989984915	0.98007
N	25	25
Sum	23.8640	25.0000
Mean	0.95456	1.00038
Mean Deviation		1
Std		1.00019
Covariance		1.047802

Table 2.1.4

Irregular Area (inch²)	 d 	d²
11.6360	0.907275	0.823147
12.3320	0.961543	0.924564
12.2260	0.953278	0.908738
14.5050	1.130974	1.279103
14.5050	1.130974	1.279103
15.3660	1.198108	1.435462
12.3260	0.961075	0.923665
12.2500	0.955149	0.91231
12.1100	0.944233	0.891576
12.3020	0.959204	0.920071
14.7210	1.147816	1.317482
16.1517	1.25937	1.586012
10.3519	0.807152	0.651494
12.1400	0.946572	0.895999
12.2180	0.952654	0.90755
12.2800	0.957488	0.916784
13.5800	1.058851	1.121165
14.6325	1.140916	1.301689
12.1425	0.946767	0.896368
12.1425	0.946767	0.896368
12.1425	0.946767	0.896368
12.1425	0.946767	0.896368
12.1425	0.946767	0.896368
12.1425	0.946767	0.896368
12.1425	0.946767	0.896368
N	25	25
Sum	320.6306	25.0000
Mean	12.825224	1.01082
Mean Deviation		1
Std		1.005395
Covariance		0.078392

Table 2.1.5

Regular Area (inch²)	 d 	d²
0.8500	0.925007	0.855638
0.8050	0.876036	0.767439
0.8640	0.940242	0.884056
1.0525	1.145376	1.311887
1.0530	1.14592	1.313134
1.0600	1.153538	1.33065
0.8460	0.920654	0.847604
0.8450	0.919566	0.845601
0.8340	0.907595	0.823729
0.8360	0.909772	0.827684
0.9734	1.059296	1.122108
1.0357	1.127094	1.27034
1.0435	1.135582	1.289547
0.8310	0.90433	0.817813
0.8260	0.898889	0.808002
0.8280	0.901066	0.811919
1.0680	1.162244	1.350811
1.0583	1.151688	1.326385
0.8206	0.893013	0.797472
0.8206	0.893013	0.797472
0.8206	0.893013	0.797472
1.0802	1.175521	1.381849
0.8206	0.893013	0.797472
0.8206	0.893013	0.797472
1.0802	1.175521	1.381849
N	25	25
Sum	22.9728	25.0000
Mean	0.918912	1.014216
Mean Deviation		1
Std		1.007083
Covariance		1.095951

2.2 PRESENTATION OF TABLE OF DERIVED RESULTS

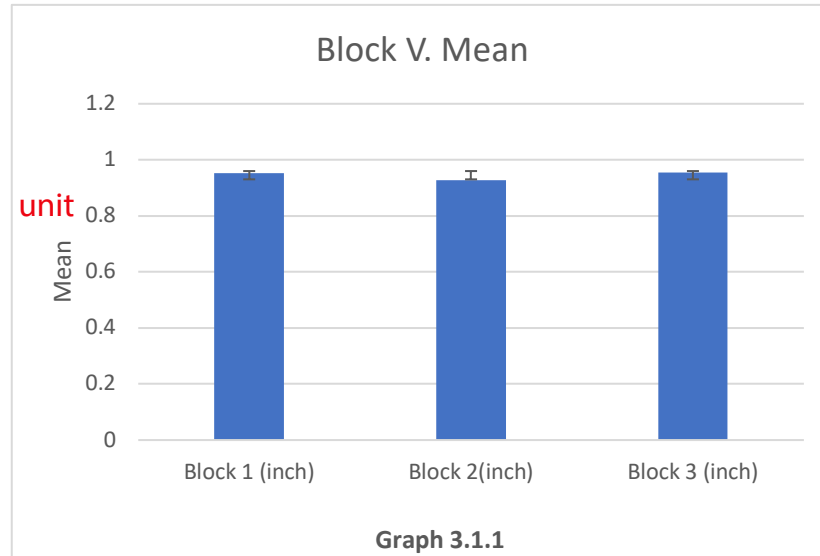
Table 2.2.1			
	Block 1	Block 2	Block 3
Mean	23.8180	0.92808	1.00038
Mean Deviation	1	1	1
Standard Deviation	1.000449	1.000249	1.00019
Covariance	1.050098	1.077762	1.047802

Table 2.2.2		
	Irregular	Regular
Mean	12.82522	0.918912
Mean Deviation	1	1
Standard Deviation	1.005395	1.007083
Covariance	0.078392	1.095951

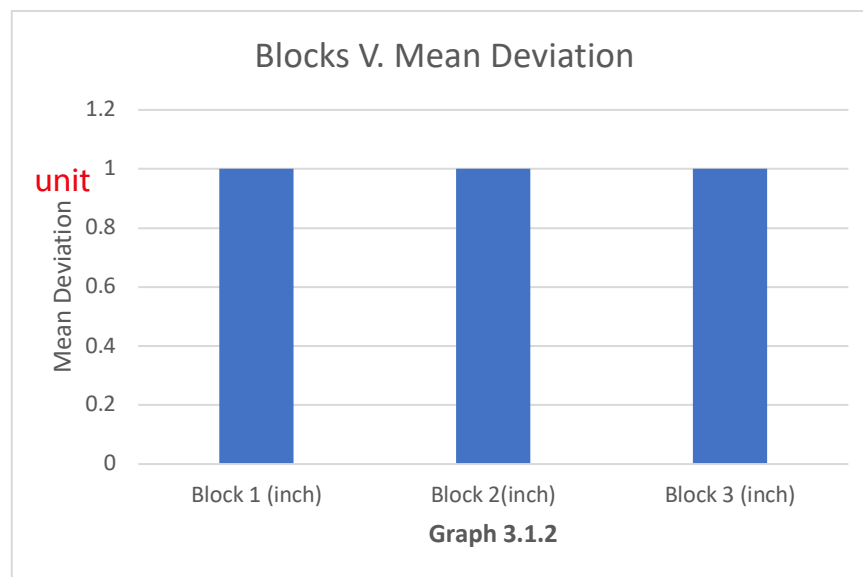
CHAPTER 3

ABILITY TO INTERPRET EXPERIMENTAL DATA

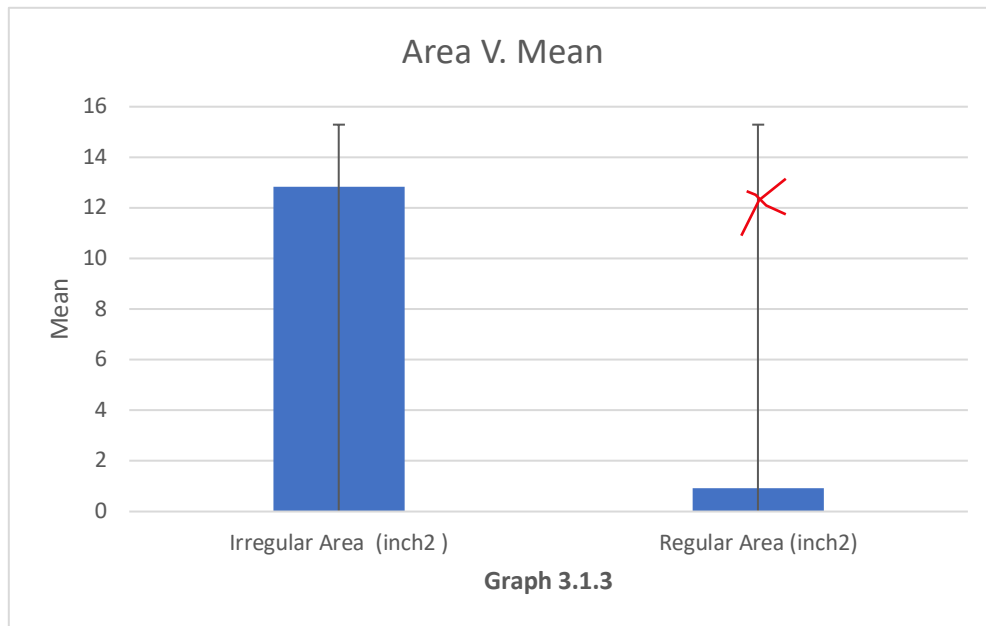
3.1 Presentation of Graphs/Figures and Interpretation of Results Presented by each Graph/Figure



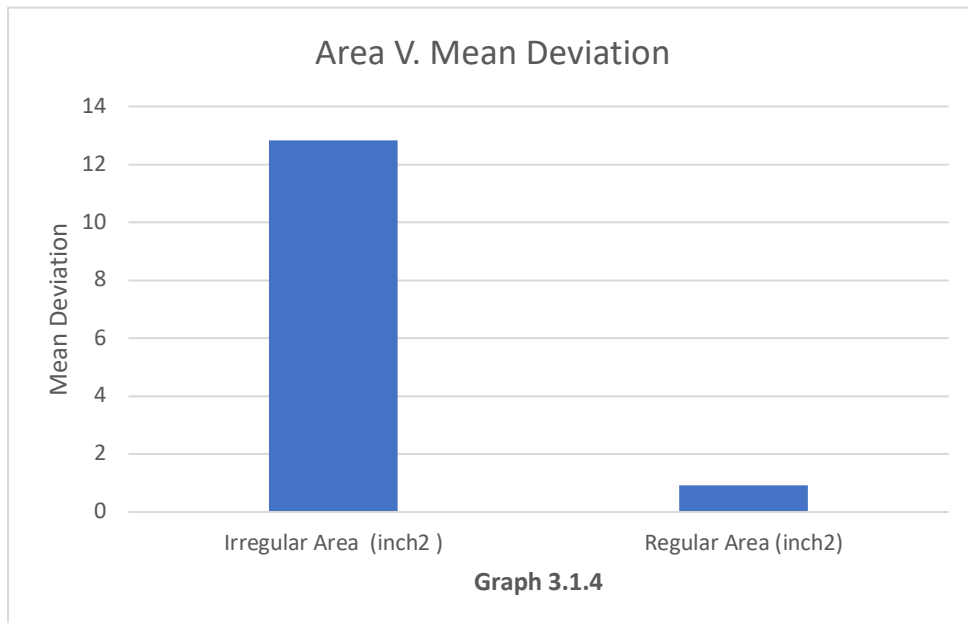
Discussion: This graph shows the relationship between the mean of the thickness of the blocks in inches. We also include error bars with a standard deviation of 1. The error bars show us that the errors based on the standard deviation are very small.



Discussion: This graph shows us the relationship between the mean deviations of the blocks. All the blocks had the same mean deviation and the mean deviation tells us how far our data points are from the mean, this tells us that all the data points were equally as far from the mean across all 3 blocks.



Discussion: This graph shows us the relationship between the means of the regular and irregular area. The mean of the irregular area is much larger, this correlates with the fact that the shape itself was much larger than the shape with a regular area. The error bar for the regular area is therefore also much larger since the data set that it is being compared to is so vastly different.



Discussion: This graph shows us the relationship between the mean deviation and the area. The mean deviation of this graph shows us how the values are related to the mean. The MD for the regular area is much smaller than the MD for the irregular area. This again stems from the fact that the area itself for the irregular area is much larger.

3.2 Conclusions based on experiments and results

It was determined that the wooden blocks had a very similar mean and the same mean deviation. For the area calculated by the planimeter it was determined that the regular area was much smaller than the irregular area, therefore both the mean deviation and the mean varied greatly.

3.3 Recommendations

One recommendation I have is that next time we should take the data twice for each person that will make the data set larger and will make our results more accurate.

BELOW AVERAGE

Letter of Transmittal

Myles Woodfork
Mechanical Engineering Student
100 University Dr.
Prairie View, Texas 77446
Cell: 713-878-2126
E-mail: mwoodfork@pvamu.edu

Dr. Mingli Han
Measurement Laboratory Instructor
Prairie View A&M University
S. R. Collins Engineering Technology Building
Room 311

September 28, 2021

Dear Dr. Han:

The following pages are a detailed report for lab 1 of MCEG 3011 Measurement Laboratory, "Precise Measurement Using Micrometers & Introduction to Statistical Analysis of Experimental Data". This report addresses the use of micrometers for precise measurements as well as the use of statistical analysis of experimental data using the mean, deviation, the mean deviation and the standard deviation. The lab was performed on January 30, 2019 and was submitted on February 13, 2019.

If you have any questions or concerns, please call or email me at any time.

Sincerely,

Myles Woodfork
Enclosure: Lab Report

**MECHANICAL ENGINEERING DEPARTMENT
PRAIRIE VIEW A&M UNIVERSITY**



MCEG 3101 MEASUREMENT LABORATORY

Fall 2021 Section P01

LABORATORY REPORT ON

“Measurement Using Micrometers and Statistical Analysis of Data”

**Conducted on
August 31, 2021**

**Submitted by
Myles Woodfork**

**On
September 28, 2021**

To

**Dr. Mingli Han
*Measurement Laboratory Instructor***

**MECHANICAL ENGINEERING DEPARTMENT
MEASUREMENT LABORATORY GRADING SHEET
FALL 2021 SECTION P01**

Title of Experiment: _____

Name: _____ Myles Woodfork _____

Date Lab was Performed: _____ Report Due Date: _____

<i>Ability to Conduct Experiments</i>	MAX	Your Score	Comments
Ability to demonstrate general lab safety (by your conduct and observations).	3	0	
Ability to follow the procedure and properly rephrasing the procedure to reflect what you did during the experiment.	7	7	
Ability to demonstrate knowledge of how equipment function, their limitations, and the uncertainty associated with reading the instruments.	5	5	
Ability to collect and record the raw data using appropriate units of measurement and identify the dependent and independent variables in the experiment.	5	5	
Total for Ability to Conduct Experiments	20	20	
Percentage for this Performance Criteria			
<i>Ability to Analyze and Interpret experimental Data in a Formal Report</i>			
Report format (Ability to properly format and present a technical report)	13	5	
Provides appropriate abstracts for the experimental report	5	3	
Ability to analyze the data using appropriate software to generate the required parameters using consistent units	27	5	
Ability to present the data (raw /derived) in tabular and graphical form to meet the objectives and to aid in interpretation.	14	7	
Ability to discuss the raw and derived data/graphs and assess the validity of the results in relation to the underlying theory and expected trends.	14	8	
Ability to draw appropriate and reasonable conclusions in relations to each of the experimental objectives. One conclusion statement for each objective.	7	7	
Total for Ability to Analyze and Interpret experimental Data	80		
TOTAL FOR THIS LAB		52	

ABSTRACT

The purpose of this lab was to take accurate measurements of both 3 blocks and 2 shapes, both regular and irregular. And be able to use knowledge gained from the first lab to jot down observations obtained by raw data collected during the actual lab itself.

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~~Statistical Analysis of Data on Linear Measurement Using Dial Calipers and Area Measurement Using Planimeter~~

Objectives:

The objectives of the experiment are to:

1. Learn the use of dial calipers and planimeter for precise measurements.
2. Introduce the use of statistical analysis and Chauvenets Criteria of experimental data using the mean, deviation, the mean deviation and the standard deviation.
3. Plot histograms for a set of experimental data represented by the mean and the standard deviation in the form of $(x_m \pm \sigma)$

Theory

Statistical Analysis of Experimental Data

In many situations, it is necessary to conduct several set of experiments to ensure that the statistical accuracy of the results can be determined. A number of statistical parameters are needed to determine the statistical accuracy of the experimental results. The statistical parameters to be discussed in this section include the mean, the deviation of each data from the mean, the average deviation, and the standard deviation or the root mean square deviation.

The Mean: The mean x_m of a set of n data in which each data is represented by x_i ($i=1$ to n) is given by

$$x_m = \frac{1}{n} \sum_{i=1}^n x_i \quad (1)$$

The Deviation: The deviation d_i of a set of n data in which each data is represented by x_i ($i=1$ to n) is given by

$$d_i = x_i - x_m \quad (2)$$

Note that the average of the deviations of all the data is zero since the sum of the deviation is zero.

The Mean Deviation: The average of the absolute values of the deviations is however not zero, and is given by

$$\left| \bar{d}_i \right| = \frac{1}{n} \sum |x_i - x_m| \quad (3)$$

The Standard Deviation: The standard deviation is also known as the root mean square deviation. It is one of the most important statistical parameters that are used to ascertain the accuracy as well as the confidence one will have in the value of the measured data. The standard deviation for a very large set of data is given by

$$\sigma = \left[\frac{1}{n} \sum_{i=1}^n (x_i - x_m)^2 \right]^{1/2} \quad (4)$$

When the number of data is not large (less than 20 for example), the sample standard deviation is given by

$$\sigma = \left[\frac{\sum (x_i - x_m)^2}{n-1} \right]^{1/2} \quad (5)$$

The Covariance: COV=Standard Deviation/Mean

Chauvenets Criterion for Rejecting Data

There are instances when an experimenter would have data that that appears to be bad or out of place in comparison to the other data. When this occurs, a decision has to be made as to whether this was caused by some type of experimental blunder and thus should be neglected or that the data was the result of an unknown physical phenomenon. To answer this problem, we need to first calculate the standard deviation of the set of data including the data in question and then analyze the data using the Gaussian or Normal distribution function. The normal distribution function $P(x_m)$ gives the probability that a measurement x , will lie between $x_m + x_1$ and $x_m - x_1$, where x_m is the mean of the set of data. $P(x_1)$ is given by

$$P(x_1) = \int_{x_m - x_1}^{x_m + x_1} \frac{1}{\sigma \sqrt{2\pi}} e^{-(x - x_m)^2 / 2\sigma^2} dx \quad (6)$$

With a change of variables $\eta = \frac{x - x_m}{\sigma}$

$$P(\eta_1) = \int_{-\eta_1}^{\eta_1} \frac{1}{\sigma \sqrt{2\pi}} e^{-\eta^2 / 2} d\eta \quad (7)$$

With this probability function, we can calculate the probability for a data to fall within 1,2,3,4,5 etc. standard deviations from the mean, as well as the probability for the data to fall outside these deviations from the mean. Table 1 gives these probabilities.

Table 1 Probability of a Data Falling Within Specified Number of Standard Deviations

Number of Standard Deviations	Probability of Data falling within the number of standard deviations	Probability of data falling outside the number of standard deviations
1	0.68268	0.31732
2	0.95450	0.0455
3	0.9973	0.0027
4	0.9999366	0.0000634

From the table, it is seen that it becomes highly unlikely for data to fall outside of very large standard deviations from the mean. This information can be used to detect data that may be bad. Obviously, the likelihood of a data falling several standard deviations outside the mean is very small and this can be an indicator that the data is bad.

A standard way of using this strategy to detect bad data is through the application of Chauvenet's criterion. Chauvenet's criterion states that a reading may be rejected if the probability of obtaining the particular deviation from the mean is less than $1/2n$, where n is the number of readings. Using this criterion and the normal probability distribution function, for any number of experimental data, n , the maximum acceptable deviation from the mean can be determined as presented in Table 2.

Table 2 Maximum Acceptable Deviation Ratio as a Function of the Number of Readings

Number of Readings	Ratio of maximum acceptable deviation to standard deviation, $ d_{\max} /\sigma$
3	1.38
4	1.54
5	1.65
6	1.73
7	1.80
10	1.96
15	2.13
25	2.33
50	2.57
100	2.81
300	3.14
500	3.29
1000	3.48

Apparatus

The Dial Caliper

The Planimeter

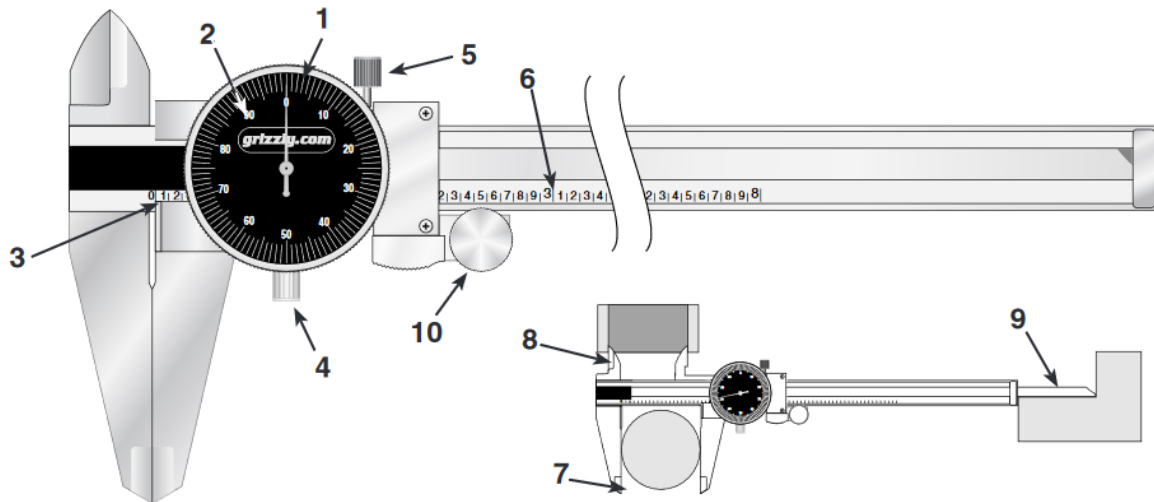


Figure 1 Dial Caliper

1. The distance between the **Lines** equals 0.001" (one thousandths of an inch).
2. The **Dial Numbers** represent 0.010" (ten thousandths of an inch).
3. Each number on the **Revolution Scale** represents one full rotation of the needle and is equal to 0.100" (one hundred thousandths or 1/10 of an inch). The jaw index indicates which number is read.

4. The **Dial Lock** secures the dial after zero is set. Clean the jaw faces of any dirt or dust and close the jaws together. If the hand is not on “0” then you can turn the dial to align it to “0”. Once aligned, lock down the bezel with the dial lock.
5. The **Caliper Lock** secures the dial to the body, maintaining a measurement.
6. The **Inch Markers** denote each full inch of measurement.
7. The **External Caliper Jaws** are used for external measurements.
8. The **Internal Jaws** are used for internal measurements.
9. The **Depth Blade** is used to gauge depth.
10. The **Thumbwheel** is used to move the dial assembly along the caliper body.

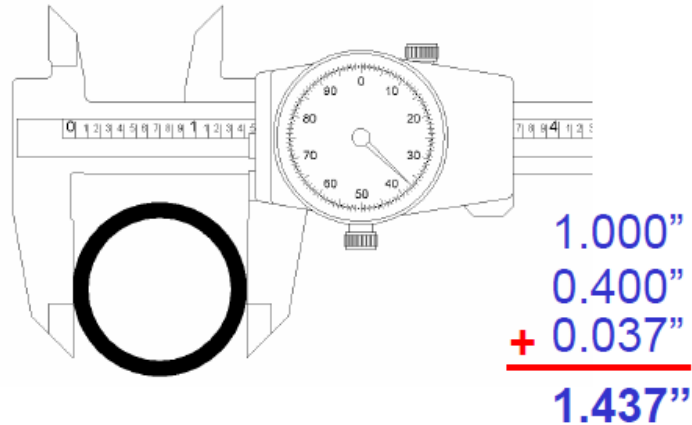


Figure 2 Dial Caliper Reading Example

Reference: Grizzly Industrial Inc.

The Planimeter

The planimeter, shown in Figure 3, is used to measure a closed area by starting at a given point on the perimeter of the area and moving the tracing point along the perimeter until it is back at the original starting point. The area enclosed by the perimeter is recorded on the electronic display of the instrument.

(Provide the Mathematical theory for the Area Computation by a Planimeter)



Figure 3 The Planimeter

Procedure

1. Study the information on “**Parts and How to Use a Vernier and Planimeter**” provided above and from several information available on the web.
2. Identify the three wooden blocks numbered 1, 2, and 3.
3. Measure, to 0.01 mm the thickness of each block and record your reading on the personal table provided to you, ensuring that other members in your group do not see your measurement in order to eliminate bias in the measurements.
4. Repeat step 3 for block 2 and 3.
5. Use the planimeter to measure the irregular area 1 and the regular area 2
6. Steps 1 through 5 should be repeated by each member in the lab group.
7. When all members in the group complete the measurements, the group leader should collect the table from the members of the group and include the group number on the first page.
8. The group leader should submit the results to the course instructor.
9. The course instructor will collect the results from all of the groups.
10. The course instructor will redistribute a set of the results from a group to the group leader in another group.
11. The group leaders should record the data for the group given to the leader on the master table in the classroom before the end of the class.
12. Each student will make a photographic image of the master tables containing the entire results or the course instructor will scan and post the master results on e-course for all students to access.

Table 3 Raw Experimental Data for Measurements of thickness of Wooden Blocks Using Vernier Caliper

Block 1 (inch)	d	d ^2	d /σ
0.9670	0.02541667	0.000646	0.509299
0.9450	0.04741667	0.002248	0.950135
0.9430	0.04941667	0.002442	0.990211
0.9400	0.05241667	0.002748	1.050325
0.9400	0.05241667	0.002748	1.050325
0.9380	0.05441667	0.002961	1.090401
1.0500	0.05758333	0.003316	1.153855
0.9500	0.04241667	0.001799	0.849945
0.9450	0.04741667	0.002248	0.950135
1.0450	0.05258333	0.002765	1.053665
0.9410	0.05141667	0.002644	1.030287
0.9430	0.04941667	0.002442	0.990211
0.9410	0.05141667	0.002644	1.030287
0.9400	0.05241667	0.002748	1.050325
0.9470	0.04541667	0.002063	0.910059
0.9420	0.05041667	0.002542	1.010249
0.9470	0.04541667	0.002063	0.910059
0.9520	0.04041667	0.001634	0.809869
0.9460	0.04641667	0.002155	0.930097
0.9460	0.04641667	0.002155	0.930097
0.9440	0.04841667	0.002344	0.970173
0.9380	0.05441667	0.002961	1.090401
0.946	0.04641667	0.002155	0.930097
0.944	0.04841667	0.002344	0.970173
0.938	0.05441667	0.002961	1.090401

Block 2(inch)	d	d ^2	d /σ
0.9340	0.03275	0.001073	0.731474
0.9440	0.02275	0.000518	0.508123
0.9310	0.03575	0.001278	0.798479
0.9370	0.02975	0.000885	0.664469
0.9370	0.02975	0.000885	0.664469
0.9320	0.03475	0.001208	0.776144
0.9230	0.04375	0.001914	0.97716
0.9300	0.03675	0.001351	0.820814
0.9320	0.03475	0.001208	0.776144
0.9250	0.04175	0.001743	0.93249
0.9260	0.04075	0.001661	0.910155
0.9260	0.04075	0.001661	0.910155
0.9290	0.03775	0.001425	0.84315
0.9320	0.03475	0.001208	0.776144
0.9350	0.03175	0.001008	0.709139
0.9370	0.02975	0.000885	0.664469
0.9320	0.03475	0.001208	0.776144
0.9320	0.03475	0.001208	0.776144
0.9300	0.03675	0.001351	0.820814
0.9420	0.02475	0.000613	0.552793
0.9270	0.03975	0.00158	0.88782
0.9300	0.03675	0.001351	0.820814
0.942	0.02475	0.000613	0.552793
0.927	0.03975	0.00158	0.88782
0.83	0.13675	0.018701	3.054323

Block 3 (inch)	d	d ^2	d /σ
0.9530	0.041333	0.001708	0.922378
0.9470	0.047333	0.00224	1.056272
0.9530	0.041333	0.001708	0.922378
0.9430	0.051333	0.002635	1.145534
0.9430	0.051333	0.002635	1.145534
0.9470	0.047333	0.00224	1.056272
1.0390	0.044667	0.001995	0.996764
0.9600	0.034333	0.001179	0.766169
0.9500	0.044333	0.001965	0.989325
0.9460	0.048333	0.002336	1.078587
0.9460	0.048333	0.002336	1.078587
0.9500	0.044333	0.001965	0.989325
0.9530	0.041333	0.001708	0.922378
0.9420	0.052333	0.002739	1.16785
0.9480	0.046333	0.002147	1.033956
0.9590	0.035333	0.001248	0.788485
0.9440	0.050333	0.002533	1.123219
0.9440	0.050333	0.002533	1.123219
0.9570	0.037333	0.001394	0.833116
0.9650	0.029333	0.00086	0.654591
0.9600	0.034333	0.001179	0.766169
0.9450	0.049333	0.002434	1.100903
0.965	0.029333	0.00086	0.654591
0.96	0.034333	0.001179	0.766169
0.945	0.049333	0.002434	1.100903

Table 4 Raw Experimental Data for Measurements of Irregular and Regular Areas Using Planimeter

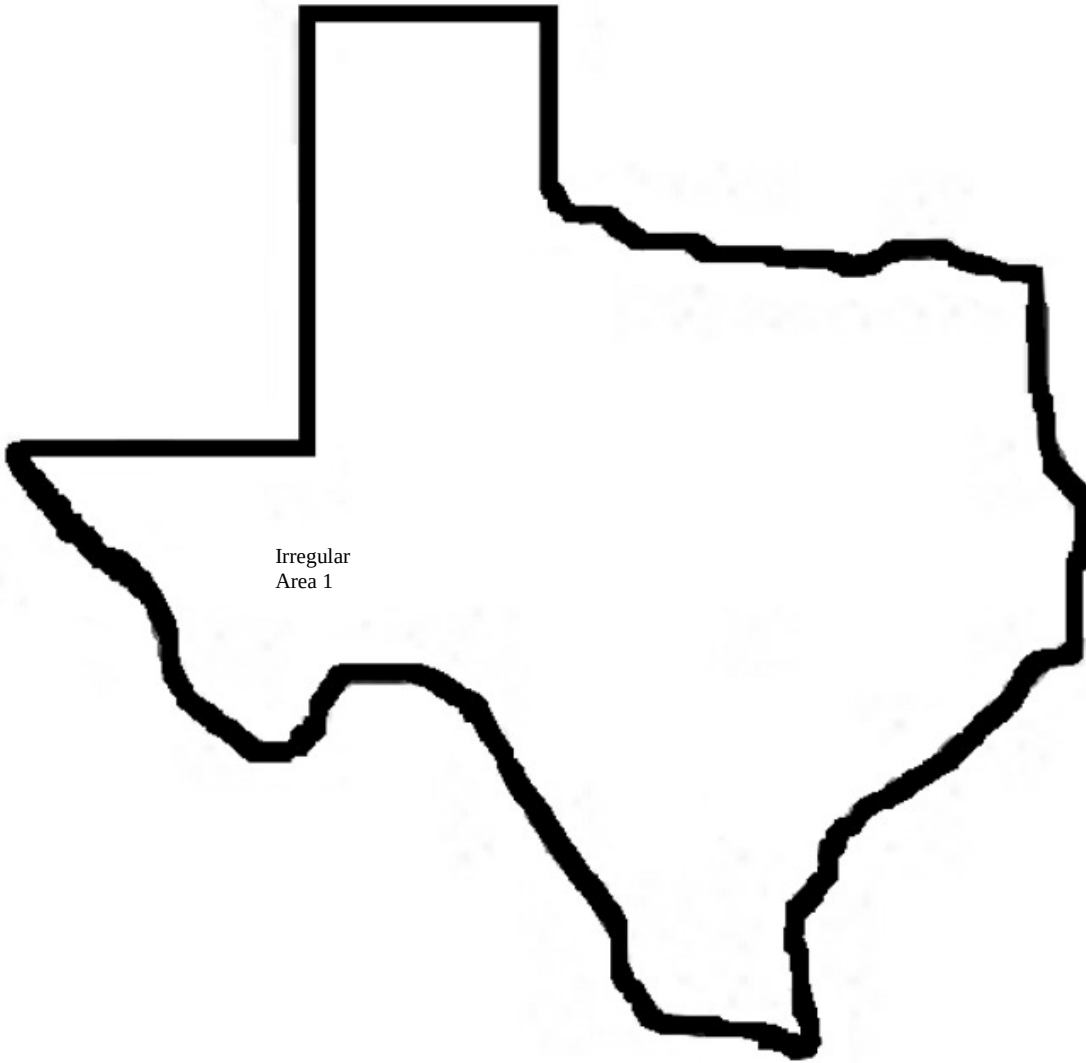
[illegible]

Regular Area (inch2)	d	d ^2	d /σ
0.8500	0.1072	0.011492	0.904995
0.8050	0.1522	0.023165	1.28489
0.8640	0.0932	0.008686	0.786805
1.0525	0.0953	0.009082	0.804533
1.0530	0.0958	0.009178	0.808754
1.0600	0.1028	0.010568	0.867849
0.8460	0.1112	0.012365	0.938763
0.8450	0.1122	0.012589	0.947205
0.8340	0.1232	0.015178	1.040068
0.8360	0.1212	0.014689	1.023184
0.9734	0.0162	0.000262	0.136762
1.0357	0.0785	0.006162	0.662706
1.0435	0.0863	0.007448	0.728554
0.8310	0.1262	0.015926	1.065395
0.8260	0.1312	0.017213	1.107605
0.8280	0.1292	0.016693	1.090721
1.0680	0.1108	0.012277	0.935386
1.0583	0.1011	0.010221	0.853498
0.8206	0.1366	0.01866	1.153193
0.8206	0.1366	0.01866	1.153193
0.8206	0.1366	0.01866	1.153193
1.0802	0.123	0.015129	1.03838
0.8206	0.1366	0.01866	1.153193
0.8206	0.1366	0.01866	1.153193
1.0802	0.123	0.015129	1.03838

Areas to be Measured Using the Planimeter

Regular
Area 2

Irregular
Area 1



Chapter 2: Analysis and Lab Report

Table 3 Summary of Computed Results

	Block 1	Block 2	Block 3
Mean, Xm	0.9924	0.9667	0.9943
Mean DV	0.0505	0.0402	0.0451
STDV	0.04991	0.04477	0.04481
COV	0.05029	0.04631	0.04506



Table 4 Summary of Computed Results

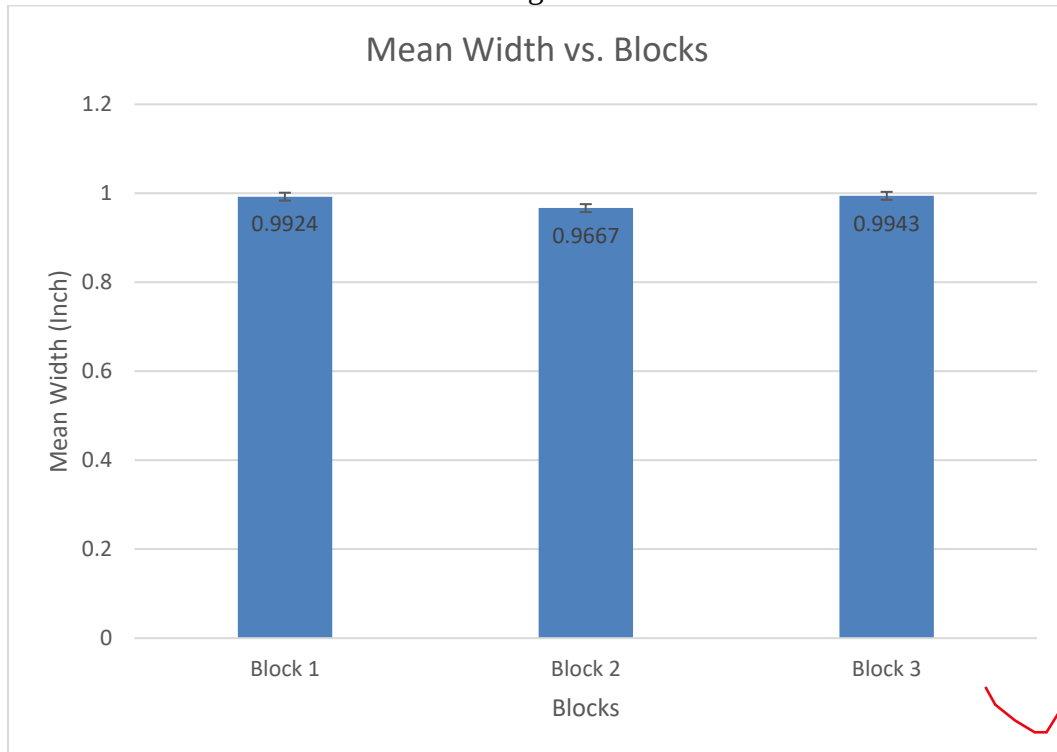
	Irregular Area (Inch ²)	Regular Area (Inch ²)
Mean, Xm	13.3596	0.9572
Mean DV	1.3853	0.1176
STDV	1.4667	0.1185
COV	0.1098	0.1238



Chapter 3 Ability to Interpret Experimental Data

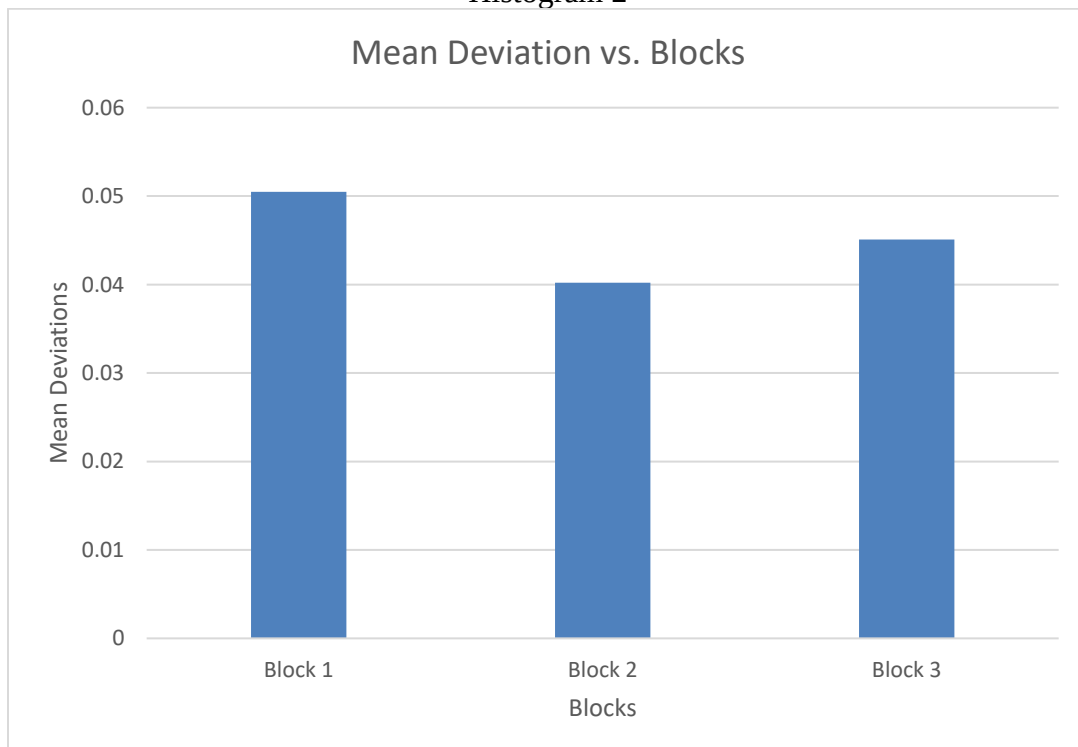
~~Chapter 3: Histograms for the Three Blocks measured for Width with Vernier Calipers~~

~~Histogram 1~~



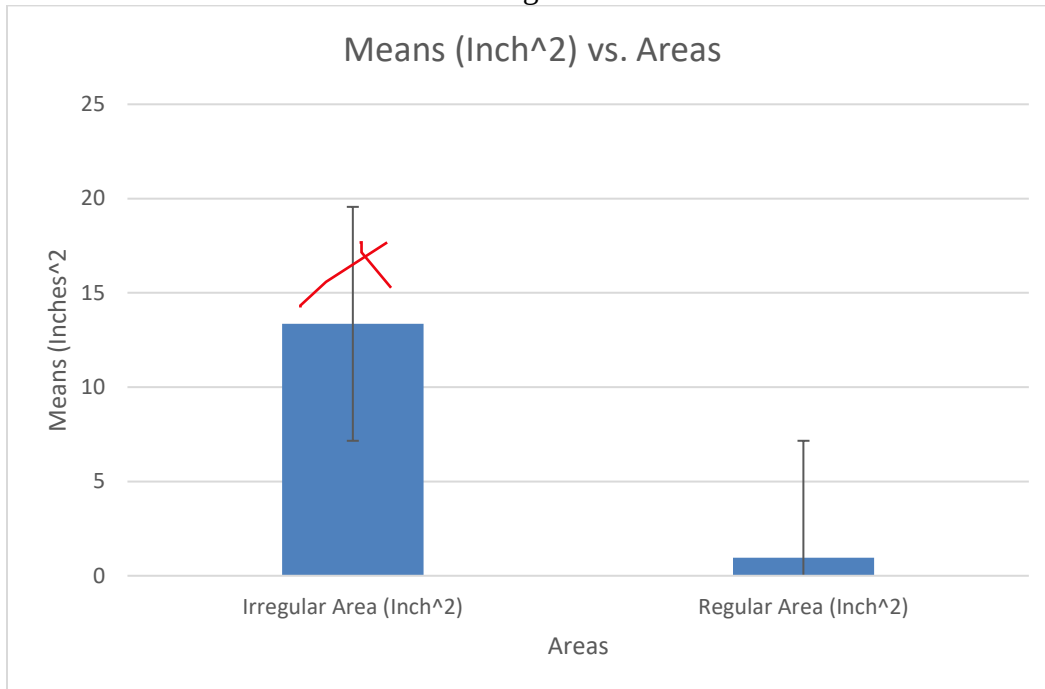
Histogram 3.1 give a caption.

Histogram 2

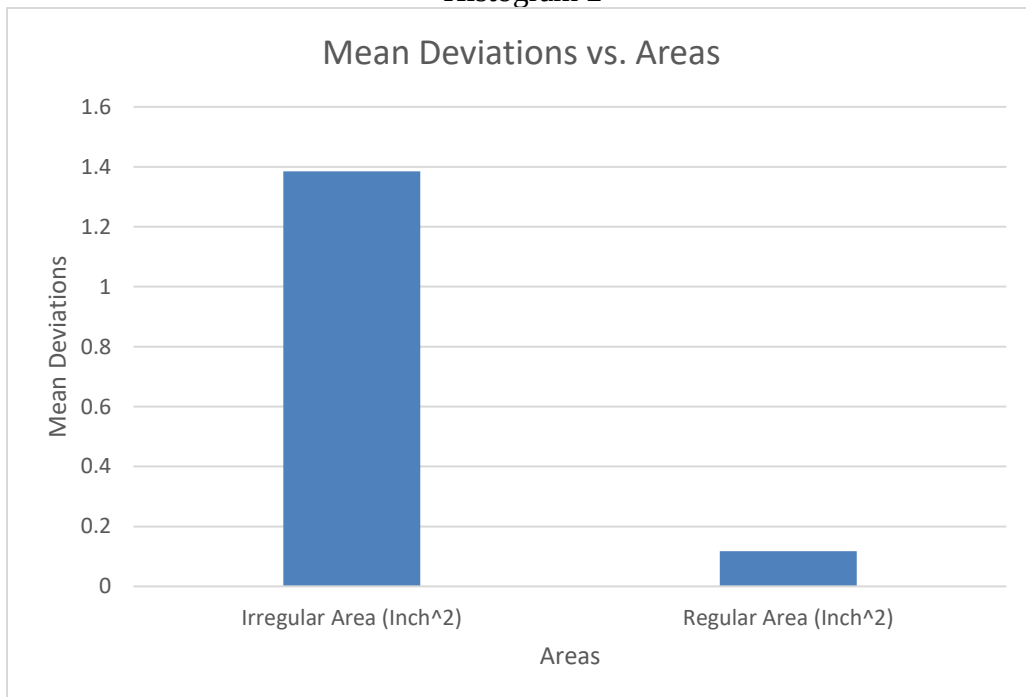


Histograms for the Areas of both Regular and Irregular Shapes measured by a Planimeter

Histogram 1



Histogram 2



3.2 Conclusion and Discussions based on results

It seemed throughout this lab that all blocks were fairly similar in width, block 2 being ever so slightly shorter than the other two around it. As far as the Areas, the Irregular shape as expected had a much bigger area and much bigger numbers to work with than the much smaller regular shape, but their averages and deviations were all still close to one another with respect to the shape they represented.

3.3 Recommendations

This lab was fairly straightforward in concept and did not take long to carry out. It was a wonderful lab to really drive home the basics of both excel and deviations.

**MEASUREMENT AND INSTRUMENTATION LABORATORY
FALL 2021**

LABORATORY REPORT # 3

TOPICS COVERED IN LABORATORY EXPERIMENT #3

**EXPERIMENT #3
CALIBRATION OF PRESSURE GAUGE AND PRESSURE
TRANSDUCERS USING THE DEAD WEIGHT TESTER**

The objectives of the experiment are to:

- 1. To perform a pressure gauge calibration using a dead weight tester.**
- 2. To perform a pressure transducer calibration using a dead weight tester**
- 3. To use EES to determine the calibration equation using a curve fit.**

**MEASUREMENT AND INSTRUMENTATION LABORATORY
FALL 2021**

LABORATORY HANDOUT FOR EXPERIMENT 3

**CALIBRATION OF PRESSURE GAUGE AND PRESSURE
TRANSDUCERS USING THE DEAD WEIGHT TESTER**

CALIBRATION OF PPRESSURE GAUGE AND PRESSURE TRANSDUCERS USING THE DEAD WEIGHT TESTER

OBJECTIVES:

1. To perform a pressure gauge calibration using a dead weight tester.
2. To perform a pressure transducer calibration using a dead weight tester
3. To use EES to determine the calibration equation using a curve fit.

THEORY: (As presented in class)

Please summarize the Pascal's pressure law discussed in class here for the theory.

APPARATUS:

Dead weight tester, weights, voltmeter and pressure transducer.

Dead Weight Tester

The dead weight tester is a device used for balancing a fluid pressure with a known weight. It is used for static calibration of pressure gauges or transducer. Its schematic is shown in Figure 1. The chamber and cylinder are filled with a clean oil for pressure generation and transmission. The gauge or transducer to be tested is installed and the piston inserted in the cylinder. The oil is pressurized by a pump. The pressure exerted on the fluid by the piston is transmitted to the gauge or transducer when the valve is opened. This pressure is varied by adding weights to the piston and pumping oil into the cylinder. The accuracy of dead weight tester is limited by two factors:

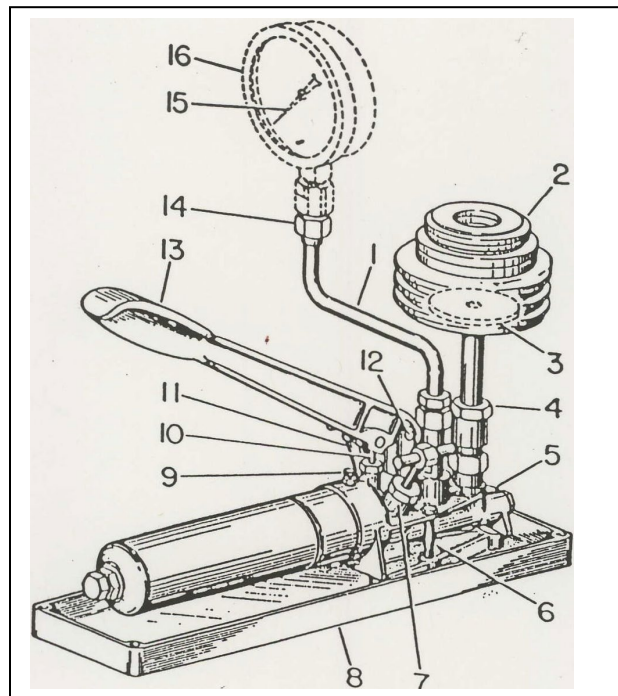
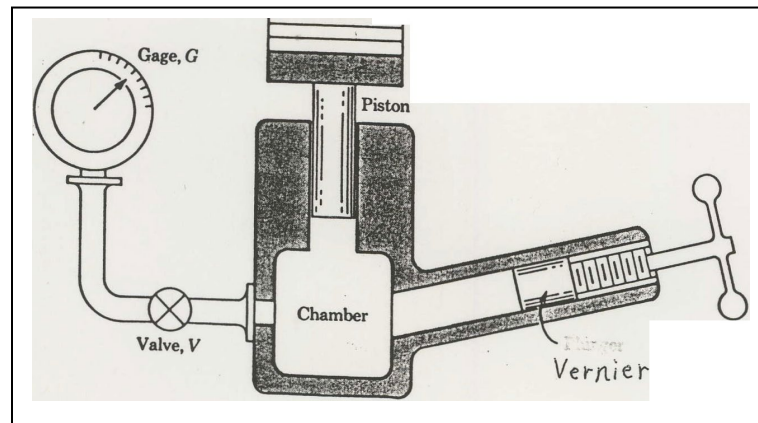


Figure 1 The Dead Weight Tester

Table 1 Parts of the Deadweight Tester

1	Offset Pipe Assy	9	Air vent
2	Dead weight	10	Piston assembly
3	Platform	11	Vernier valve
4	Dead weight cylinder	12	Clevis pin
5	Body	13	Handle
6	Bolt	14	Union nut
7	Relief valve	15	Gauge pointer
8	Drip pan	16	Gauge



- (1) The friction between the cylinder and the piston

The viscous friction between the piston and the cylinder in the axial direction is reduced by rotating the piston-weight assembly while the measurement is taken.

- (2) The uncertainty in the area of the piston

The force of the weight acts not all at the area of the piston or the area of the cylinder. There is some of the effective area between these two which depends on the clearance spacing and the viscosity of the oil. The smaller the clearance, the more closely the effective area will approximate the cross-sectional area of the piston. It can show that percentage error due to clearance varies as:

$$\text{Percent error} \sim \frac{b^3 \sqrt{(\rho P)}}{\mu D L}$$

Where: ρ = density of oil

P = pressure on the cylinder

b = clearance spacing $(D_c - D_p)/2$

μ = viscosity of oil

D_c = cylinder diameter

D_p = piston diameter

L= piston length

At high pressure there can be an elastic deformation of the cylinder which increases the clearance spacing and thus increasing the error of the test. There are two kind of pistons used on the dead weight tester for different pressure rangars of gauge or transducer. The cross section areas of pistons are different. The weights of the two pistons are the same.

PROCEDURE:

1. If the 0.5 lb piston is not already inserted in the cylinder, then insert it in the cylinder.
2. Close the valve and pump the oil into the chamber until the platform is raised up. Use the vernier valve to adjust position of the platform.
3. Rotate the platform weight assembly while the measurement is taken. Record both the weight on the platform, the True pressure calculated using $P_{\text{True}} = \text{Weight} / A_{\text{piston}}$, and pressure indicated by the pressure gauge (for the case of pressure gauge calibration) or the volts on the voltmeter (for the case of pressure transducer calibration).
4. Repeat step 3 for each increment of 0.5 lb weight until the highest reading of the pressure gauge or the pressure transducer is reached (or a predetermined value).

Report:

1. Using EES, define the variables in the table headings
2. Compute the average of the two readings of the output voltages and the output pressure on the pressure gauges
3. For Table 2, plot Generated True Pressure Versus the average voltage, and then fit the best straight line through the data points, and then plot the equation on the graph. Note the statistics of the straight line fit.
4. For Table 3, plot Generated True Pressure Versus the output on the pressure gauge, and then fit the best straight line through the data points, and then plot the equation on the graph. Note the statistics of the straight line fit.
5. Complete your report using the standard format for lab reporting.

Table 2 Raw Data for 0-50 PSI Pressure TransducerA= 0.1 in² Generated Pressure=Weight/A

Weight (lb)	Generated True Pressure (psig)	Output voltage of pressure transducer	
		Loading	Unloading
		Volts	Volts
0	0		
0.5	5		
1.0	10		
1.5	15		
2.0	20		
2.5	25		
3.0	30		
3.5	35		
4.0	40		
4.5	45		
5.0	50		

Table 3 Raw data for 0-250 Pressure Gauge psiA= 0.02 in² Generated Pressure=Weight/A

Weight (lb)	Generated True Pressure (psig)	Output on Pressure Gauge	
		Loading	Unloading
		psi	psi
0	0		
0.5	25		
1.0	50		
1.5	75		
2.0	100		
2.5	125		
3.0	150		
3.5	175		
4.0	200		
4.5	225		
5.0	250		

ABOVE AVERAGE

**MECHANICAL ENGINEERING DEPARTMENT
PRAIRIE VIEW A&M UNIVERSITY**



MCEG 3101 MEASUREMENT LABORATORY

Fall 2021 Section P01

LABORATORY REPORT ON

**“Calibration Of Pressure Gauge And Pressure Transducers Using
The Dead Weight Tester”**

**Conducted on
September 29, 2021**

**Submitted by
Heba Afzal
On
October 19, 2021**

To

**Dr. Mingli Han
*Measurement Laboratory Instructor***

MECHANICAL ENGINEERING DEPARTMENT

**MEASUREMENT LABORATORY GRADING SHEET
FALL 2021 SECTION P01**

Title of Experiment: Calibration Of Pressure Gauge And Pressure Transducers Using The Dead Weight Tester

Name: Heba Afzal

Date Lab was Performed: 9/29/2021 Report Due Date: 10/19/2021

<i>Ability to Conduct Experiments</i>	MAX	Your Score	Comments
Ability to demonstrate general lab safety (by your conduct and observations).	3	3	
Ability to follow the procedure and properly rephrasing the procedure to reflect what you did during the experiment.	7	7	
Ability to demonstrate knowledge of how equipment function, their limitations, and the uncertainty associated with reading the instruments.	5	5	
Ability to collect and record the raw data using appropriate units of measurement and identify the dependent and independent variables in the experiment.	5	5	
Total for Ability to Conduct Experiments	20		
Percentage for this Performance Criteria			
<i>Ability to Analyze and Interpret experimental Data in a Formal Report</i>			
Report format (Ability to properly format and present a technical report)	13	11	
Provides appropriate abstracts for the experimental report	5	5	
Ability to analyze the data using appropriate software to generate the required parameters using consistent units	27	27	
Ability to present the data (raw /derived) in tabular and graphical form to meet the objectives and to aid in interpretation.	14	14	
Ability to discuss the raw and derived data/graphs and assess the validity of the results in relation to the underlying theory and expected trends.	14	14	
Ability to draw appropriate and reasonable conclusions in relations to each of the experimental objectives. One conclusion statement for each objective.	7	7	
Total for Ability to Analyze and Interpret experimental Data	80		
TOTAL FOR THIS LAB		98	

Heba Afzal
Mechanical Engineering Student
9522 Bending Willow Ln
Houston Tx 77064
Cell: 832-805-5485
E-mail: hafzal@student.pvamu.edu

Dr. Mingli Han
Measurement Laboratory Instructor
Prairie View A&M University
S. R. Collins Engineering Technology Building Room 311

Dear Dr. Han:

October 19, 2021

The following pages are a detailed report for lab 3 of MCEG 3011 Measurement Laboratory, "Calibration Of Pressure Gauge And Pressure Transducers Using The Dead Weight Tester". This report addresses the calibration of pressure gauges and pressure transducers. We will also use the engineering equation solver to make tables and plots. The lab was performed on September 29, 2021 and was submitted on October 19, 2021.

If you have any questions or concerns, please call or email me at any time.

Sincerely,

Heba Afzal
Enclosure: Lab Report

Abstract

The purpose of this experiment is to calibrate a pressure gauge and pressure transducer using a dead weight tester, and to then collect the value and determine the relationship between the pressure, voltage and generated true pressure. The weights of known value are used to balance fluid pressure in the piston. We put weights of a known value on the plate on top of the piston and we pumped it until we saw the line in the slot that tells us the system was balanced. We then recorded either the voltage or pressure values at this balanced state and ran our calculation based of this data. We discovered that there was a linear relationship between voltage/pressure and GTP, where GTP was the dependent variable and either pressure or voltage were independent

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CHAPTER 1

ABILITY TO CONDUCT EXPERIMENT

OBJECTIVES:

1. To perform a pressure gauge calibration using a dead weight tester.
2. To perform a pressure transducer calibration using a dead weight tester
3. To use EES to determine the calibration equation using a curve fit.

THEORY:

Pascals law tells us that the pressure exerted anywhere in a confined incompressible fluid is transmitted equally in all directions throughout the fluid such that the pressure variations remain the same everywhere

APPARATUS:

Dead weight tester, weights, voltmeter and pressure transducer.

Dead Weight Tester

The dead weight tester is a device used for balancing a fluid pressure with a known weight. It is used for static calibration of pressure gauges or transducer. Its schematic is shown in Figure 1. The chamber and cylinder are filled with a clean oil for pressure generation and transmission. The gauge or transducer to be tested is installed and the piston inserted in the cylinder. The oil is pressurized by a pump. The pressure exerted on the fluid by the piston is transmitted to the gauge or transducer. This pressure is varied by adding weights to the piston and pumping oil into the cylinder. The accuracy of dead weight tester is limited by two factors:

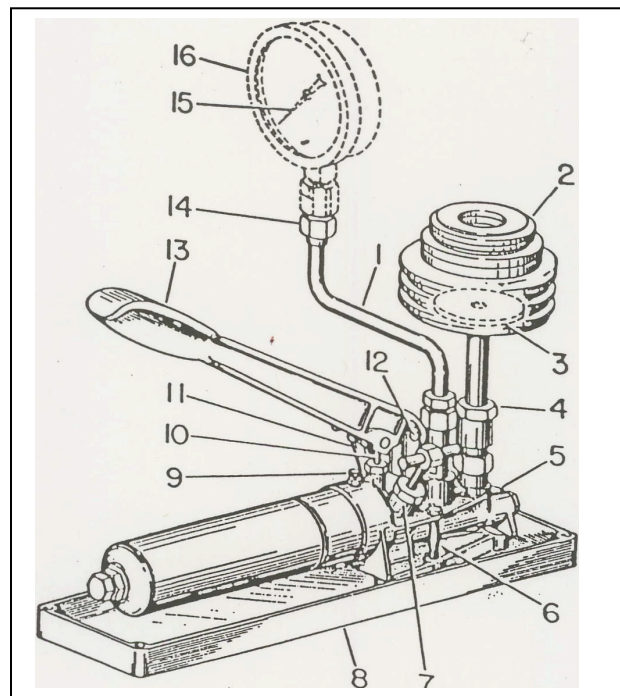


Figure 1.1 Deadweight Tester

Table 1.1 Parts of the Deadweight Tester

1	Offset Pipe Assy	9	Air vent
2	Dead weight	10	Piston assembly
3	Platform	11	Vernier valve
4	Dead weight cylinder	12	Clevis pin
5	Body	13	Handle
6	Bolt	14	Union nut
7	Relief valve	15	Gauge pointer
8	Drip pan	16	Gauge

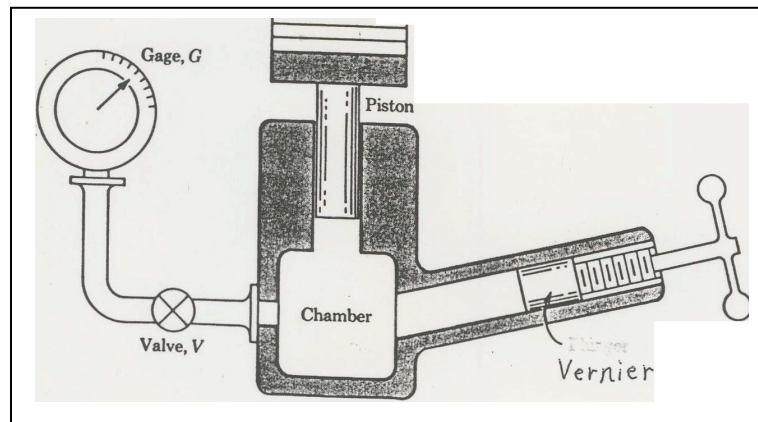


Figure 1.2 Pressure Gauge diagram

- (1) The friction between the cylinder and the piston
The viscous friction between the piston and the cylinder in the axial direction is reduced by rotating the piston-weight assembly while the measurement is taken.
- (2) The uncertainty in the area of the piston
The force of the weight acts not all at the area of the piston or the area of the cylinder. There is some of the effective area between these two which depends on the clearance spacing and the viscosity of the oil. The smaller the clearance, the more closely the effective area will approximate the cross-sectional area of the piston. It can show that percentage error due to clearance varies as:

$$\text{Percent error} \sim \frac{b^3 \sqrt{(\rho P)}}{\mu D L}$$

Where:

ρ = density of oil

P = pressure on the cylinder

b = clearance spacing $(D_c - D_p)/2$

μ = viscosity of oil

D_c = cylinder diameter

D_p = piston diameter

L = piston length

At high pressure there can be an elastic deformation of the cylinder which increases the clearance spacing and thus increasing the error of the test. There are two kind of pistons used on the dead weight tester for different pressure rangers of gauge or transducer. The cross section areas of pistons are different. The weights of the two pistons are the same.

UNCERTAINTY IN READING: With the dead weight tester and pressure transducer there could uncertainty in the data collected if for the voltmeter the user didn't wait for the value to steady, or with the pressure gauge and transducer if they took the reading before the line was in the slot or if the line had passed the slot.

Experimental Safety: Be careful not to drop the weights or play around with them. I observed no other safety concerns.

EXPIREMENTAL PROCEDURE

We began with identifying the dead weight tester with the pressure gauge and the one with the pressure transducer. We then identified the weights that we would be using. we began our calibration of the pressure gauge by first using the weight of the piston itself since it is equal to .5lbs. We closed the valve and began pumping which raised the platform until we saw the line appear in the slot, we then used the vernier valve to adjust the position of the platform if needed, we then looked at the pressure gauge and wrote down the value. We then repeat this process until the weight on the platform has reached 5 lbs. With the pressure transducer the process is the same but instead of reading the pressure of the gauge we read the value on the voltmeter after is has steadied.

1.6 PRESENTATION OF RAW EXPERIMENTAL DATA

Table 1.2 Raw Data for 0 – 50 PSI Pressure Transducer $A=0.1 \text{ in}^2$

Weight (lb)	Generated True Pressure (psig)	Output voltage of pressure transducer	
		Volts (loading)	Volts (unloading)
0		1.32	1.36
0.5		1.90	1.93
1.0		2.45	2.45
1.5		2.94	2.95
2.0		3.45	3.44
2.5		3.98	3.94
3.0		4.45	4.44
3.5		4.96	4.95
4.0		5.45	5.45
4.5		5.95	5.94
5.0		6.45	6.44

Table 1.3 Raw Data for 0 – 250 PSI Pressure Gauge $A=0.02 \text{ in}^2$

Weight (lb)	Generated True Pressure (psig)	Output on Pressure Gauge	
		psig (loading)	psig (unloading)
0		0	0
0.5		25	25.2
1.0		50	50
1.5		75.1	75
2.0		100	100
2.5		125	125
3.0		150.5	150
3.5		175	175
4.0		200	200
4.5		225	225
5.0		250	250

CHAPTER 2

ABILITY TO ANALYZE EXPERIMENTAL DATA

2.1 Detailed computer analysis of data

Figure 2.1 Pressure Transducer Equation Window

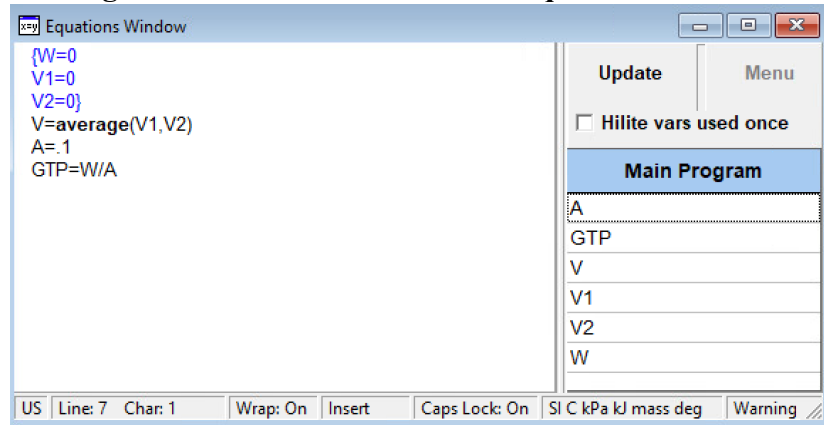
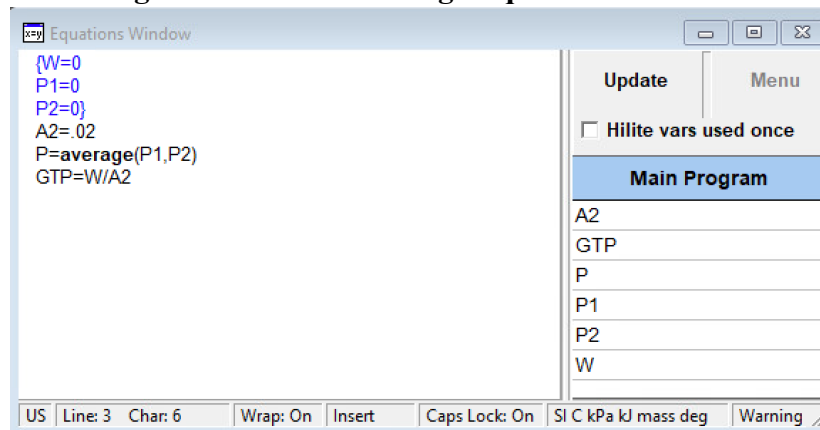


Figure 2.2 Pressure Gauge Equation Window



2.2 Presentation of Tables of derived results

Table 2.1 Pressure Transducer table of Values

Parametric Table					
Table 1					
1..11	1 W	2 GTP	3 V1	4 V2	5 V
Run 1	0	0	1.32	1.36	1.34
Run 2	0.5	5	1.9	1.93	1.915
Run 3	1	10	2.45	2.45	2.45
Run 4	1.5	15	2.94	2.95	2.945
Run 5	2	20	3.45	3.44	3.445
Run 6	2.5	25	3.98	3.94	3.96
Run 7	3	30	4.45	4.44	4.445
Run 8	3.5	35	4.96	4.95	4.955
Run 9	4	40	5.45	5.45	5.45
Run 10	4.5	45	5.95	5.94	5.945
Run 11	5	50	6.45	6.44	6.445

Table 2.2 Pressure Gauge Table of Values

Parametric Table					
Table 2					
1..11	1 W	2 GTP	3 P1	4 P2	5 P
Run 1	0	3.009E-36	0	0	0
Run 2	0.5	25	25	25.2	25.1
Run 3	1	50	50	50	50
Run 4	1.5	75	75.1	75	75.05
Run 5	2	100	100	100	100
Run 6	2.5	125	125	125	125
Run 7	3	150	150.5	150	150.3
Run 8	3.5	175	175	175	175
Run 9	4	200	200	200	200
Run 10	4.5	225	225	225	225
Run 11	5	250	250	250	250

CHAPTER 3

ABILITY TO INTERPRET EXPERIMENTAL DATA

3.1 Presentation of Graphs/Figures and Interpretation of Results Presented by each Graph/Figure

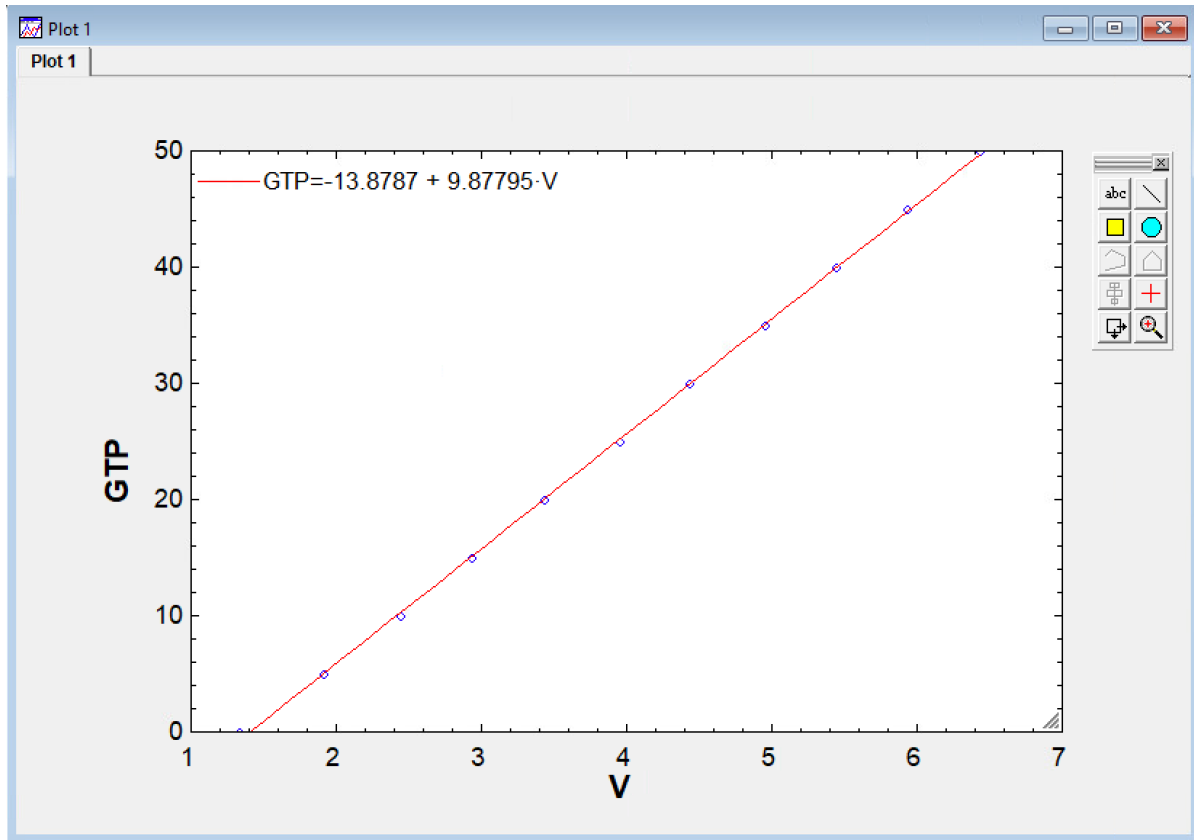


Figure 3.1 V vs. GTP

Discussion: This graph of the calculated values of the pressure transducer shows us the relationship between the the voltage observed on the voltmeter and the generated true pressure that we calculated from each data point. The GTP is dependent on the Weight and the area. The liner relationship of this graph shows us that the voltage and the GTP and directly related and as the voltage increases the GTP also increases.

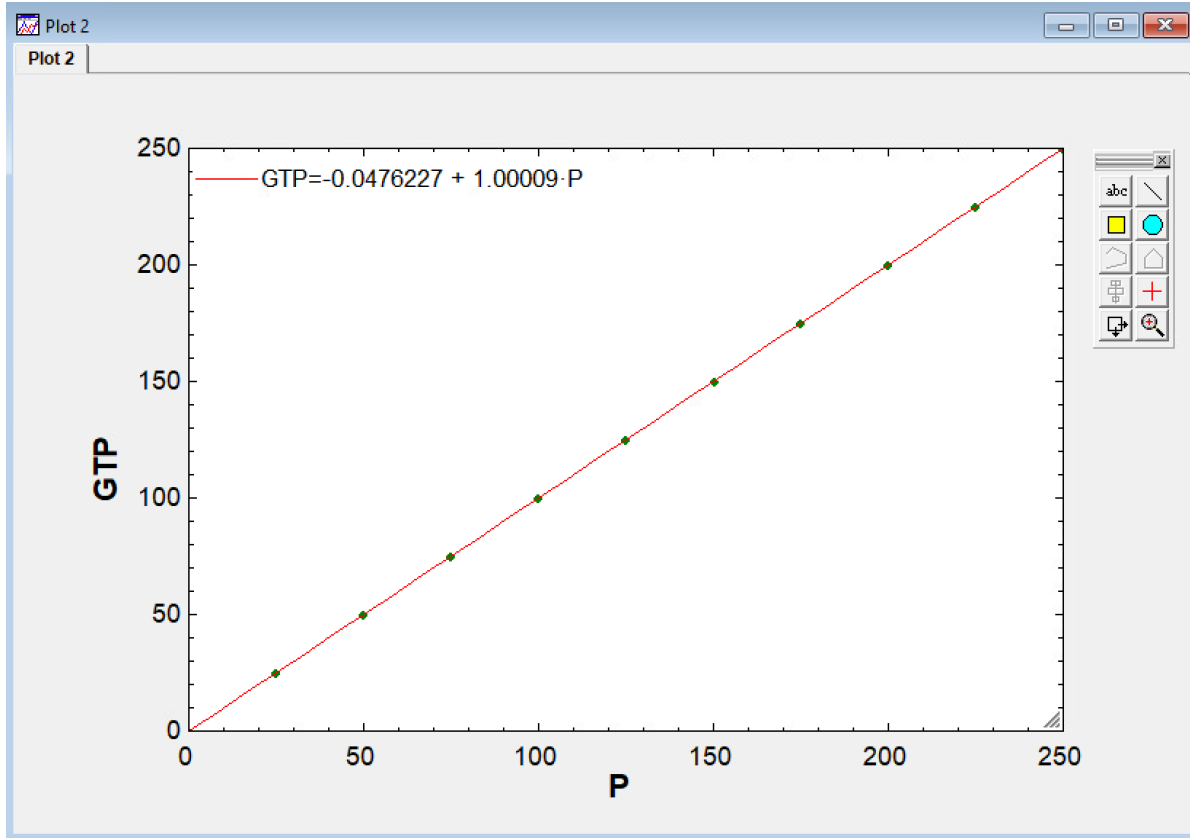


Figure 3.2 P vs. GTP

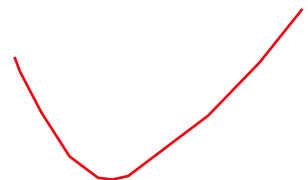
Discussion: Just like the graph that shows us the liner relationship between the voltage and the GTP, this graph of the pressure gauge shows us the relationship between the pressure in the deadweight tester and the GTP. The GTP is dependent on the area and weight, and we can see that as the pressure increases with additional weight the generated true pressure also increases linearly.

3.2 Conclusions based on each Objective and Results

During the experiment we calibrated both the pressure gauge and transducer using the dead weight tester. We recorded the values taken during the calibration and we used EES to find both the GTP and the average pressure and temperature. We then plotted the P v GTP and the V vs GTP graphs and determined that there is liner relationship between the pressure/voltage and the generated true pressure. Also, in pascals law we learned that when a incompressible fluid has a pressure change, that change is transmitted in all directions. The results of the experiment and the fact that our graphs have linear relationships proves this theory to us.

3.3 Recommendations

No recommendations



AVERAGE

**MECHANICAL ENGINEERING DEPARTMENT
PRAIRIE VIEW A&M UNIVERSITY**



MCEG 3101 MEASUREMENT LABORATORY

Fall 2021 Section P01

LABORATORY REPORT ON

**“CALIBRATION OF PRESSURE GAUGE AND PRESSURE
TRANSDUCERS
USING THE DEAD WEIGHT TESTER”**

**Conducted on
October 12, 2021**

**Submitted by
Christopher Roberts**

**On
October 19, 2021**

To

**Dr. Mingli Han
*Measurement Laboratory Instructor***

**MECHANICAL ENGINEERING DEPARTMENT
MEASUREMENT LABORATORY GRADING SHEET
FALL 2021 SECTION P01**

Title of Experiment: **“CALIBRATION OF PRESSURE GAUGE AND PRESSURE TRANSDUCERS USING THE DEAD WEIGHT TESTER”**

Name: Christopher Roberts

Date Lab was Performed: 10/12/21

Report Due Date: 10/19/21

<i>Ability to Conduct Experiments</i>	MAX	Your Score	Comments
Ability to demonstrate general lab safety (by your conduct and observations).	3	3	
Ability to follow the procedure and properly rephrasing the procedure to reflect what you did during the experiment.	7	7	
Ability to demonstrate knowledge of how equipment function, their limitations, and the uncertainty associated with reading the instruments.	5	5	
Ability to collect and record the raw data using appropriate units of measurement and identify the dependent and independent variables in the experiment.	5	5	
Total for Ability to Conduct Experiments	20		
Percentage for this Performance Criteria			
<i>Ability to Analyze and Interpret experimental Data in a Formal Report</i>			
Report format (Ability to properly format and present a technical report)	13	13	
Provides appropriate abstracts for the experimental report	5	3	
Ability to analyze the data using appropriate software to generate the required parameters using consistent units	27	27	
Ability to present the data (raw /derived) in tabular and graphical form to meet the objectives and to aid in interpretation.	14	12	
Ability to discuss the raw and derived data/graphs and assess the validity of the results in relation to the underlying theory and expected trends.	14	2	
Ability to draw appropriate and reasonable conclusions in relations to each of the experimental objectives. One conclusion statement for each objective.	7	7	
Total for Ability to Analyze and Interpret experimental Data	80	84	
TOTAL FOR THIS LAB			

Letter of Transmittal

Christopher Roberts
Mechanical Engineering Student
100 University Dr.
Prairie View, Texas 77446
Cell: (409)338-0850
E-mail: croberts27@pvamu.edu

Dr. Mingli Han
Measurement Laboratory Instructor
Prairie View A&M University
S. R. Collins Engineering Technology Building
Room 311

October 19, 2021

Dear Dr. Han:

The following pages are a detailed report for lab 3 of MCEG 3101 Measurement Laboratory, "CALIBRATION OF PRESSURE GAUGE AND PRESSURE TRANSDUCERS USING THE DEAD WEIGHT TESTER". This report addresses the use of a dead weight tester to calibrate a pressure gauge and transducer. As well as this, we will use EES to conduct further statistical analysis. The lab was performed on October 12, 2021 and was submitted on October 19, 2021.

If you have any questions or concerns, please call or email me at any time.

Sincerely,

Christopher Roberts
Enclosure: Lab Report

ABSTRACT

The Purpose of the Experiment

- The purpose of this experiment is to understand how to accurately use a dead weight tester to successfully calibrate a pressure gauge and transducer. We will be further interpreting this data by the use of statistical analysis in EES to determine the calibration equation. To assist in visualizing results we will be implementing the use of plots.

The Brief Description of Method Used

- Utilizing a dead weight tester to perform a pressure gauge calibration.
- Utilizing a dead weight tester to perform a pressure transducer calibration.

The Significant Results of the Tests

- Multiple examples of data with $|di|/\sigma$ greater than the acceptable ratio, therefore the respective data was rejected.

The Major Conclusions Drawn from the Results

- All of the blocks are very similar, with low deviations from the mean.
- Major difference in area of the two shapes.

?

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CHAPTER 1

ABILITY TO CONDUCT EXPERIMENTS

1.1 Objectives of the Experiment

The objectives of the experiment are to:

1. To perform a pressure gauge calibration using a dead weight tester.
2. To perform a pressure transducer calibration using a dead weight tester
3. To use EES to determine the calibration equation using a curve fit.

1.2 Theory Associated with Experiment

Pressure at a point in a fluid:

$$P=F/A$$

The pressure at a point in a fluid at rest is equal in all directions

$$p_x=p_y=p_z \text{ at a point } (x,y,z) \text{ in a static fluid}$$

Pascal's law or the principle of transmission of fluid-pressure is a principle in fluid mechanics that states that pressure exerted anywhere in a confined incompressible fluid is transmitted equally in all directions throughout the fluid such that the pressure variations remain the same everywhere.

1.3 Apparatus and Uncertainty in Reading Instruments

Dead weight tester, weights, voltmeter and pressure transducer.

Dead Weight Tester

The dead weight tester is a device used for balancing a fluid pressure with a known weight. It is used for static calibration of pressure gauges or transducer. Its schematic is shown in Figure 1. The chamber and cylinder are filled with a clean oil for pressure generation and transmission. The gauge or transducer to be tested is installed and the piston inserted in the cylinder. The oil is pressurized by a pump. The pressure exerted on the fluid by the piston is transmitted to the gauge or transducer. This pressure is varied by adding weights to the piston and pumping oil into the cylinder. The accuracy of dead weight tester is limited by two factors:

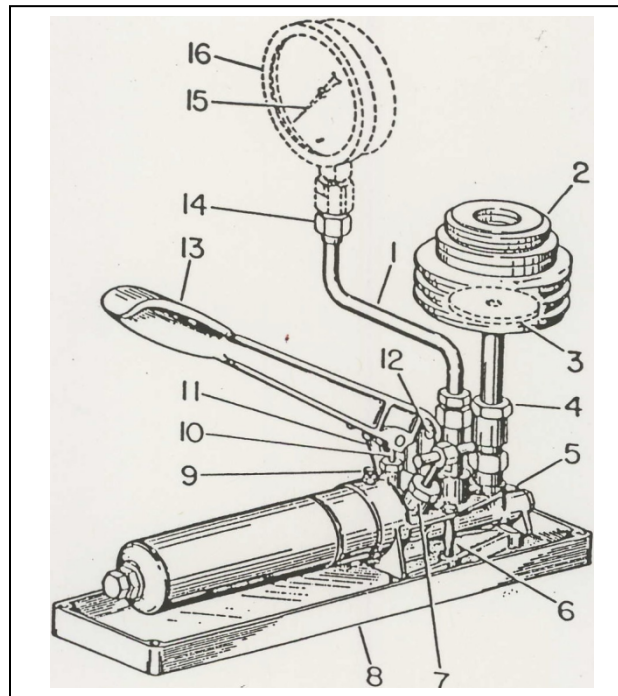


Figure 1 The Dead Weight Tester

Table 1 Parts of the Deadweight Tester

1	Offset Pipe Assy	9	Air vent
2	Dead weight	10	Piston assembly
3	Platform	11	Vernier valve
4	Dead weight cylinder	12	Clevis pin
5	Body	13	Handle
6	Bolt	14	Union nut
7	Relief valve	15	Gauge pointer
8	Drip pan	16	Gauge

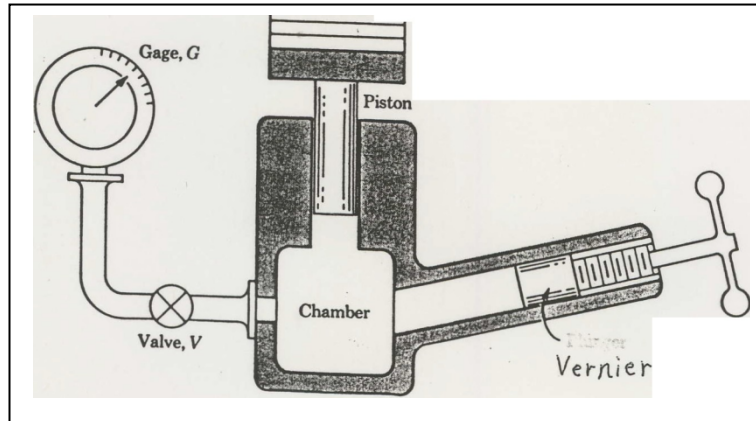


Figure 2 The Dead Weight Tester Cont'd

- (1) The friction between the cylinder and the piston
The viscous friction between the piston and the cylinder in the axial direction is reduced by rotating the piston-weight assembly while the measurement is taken.
- (2) The uncertainty in the area of the piston
The force of the weight acts not all at the area of the piston or the area of the cylinder. There is some of the effective area between these two which depends on the clearance spacing and the viscosity of the oil. The smaller the clearance, the more closely the effective area will approximate the cross-sectional area of the piston. It can show that percentage error due to clearance varies as:

$$\text{Percent error} \sim \frac{b^{3\sqrt{(\rho P)}}}{\mu DL}$$

Where:

ρ = density of oil

P = pressure on the cylinder

b = clearance spacing $(D_c - D_p)/2$

μ = viscosity of oil

D_c = cylinder diameter

D_p = piston diameter

L = piston length

At high pressure there can be an elastic deformation of the cylinder which increases the clearance spacing and thus increasing the error of the test. There are two kind of pistons used on the dead weight tester for different pressure rangers of gauge or transducer. The cross section areas of pistons are different. The weights of the two pistons are the same.

1.4 Experimental Safety

1. "Horseplay" is hazardous and will not be tolerated.
2. No student may work alone in the laboratory at any time except to prepare flow diagrams and operating procedures. When hazardous operations are conducted, arrangements should be made to have another individual present in the lab.
3. Required personal protective equipment (PPE) must be provided by the department used whenever specified by the Laboratory Director/Technician.
4. Always wear appropriate clothing (e.g. shirts, shoes) and personal protective equipment(e.g. safety glasses, lab coats, gloves) in the laboratory. Remove personal protective equipment before leaving the laboratory.
5. Sandals, open-toed shoes, high-heeled shoes, and shoes (or boots) with holes in the soles or having canvas uppers will not be worn in the laboratory. Shirts or blouses are required in the laboratories. Shorts and skirts are not permitted.
6. Each student MUST know the use and location of all first aid and emergency equipment in the laboratories, shops, and storage areas.
7. Each student must know the emergency telephone numbers to summon the fire fighters, police, emergency medical service or other emergency response services. These numbers MUST be posted at many places throughout the building.
8. Each student must be familiar with all elements of fire safety: alarm, evacuation and assembly, fire containment and suppression, rescue and facilities evaluation.

1.5 Experimental Procedure

1. The 0.5 lb piston was inserted in the cylinder.
2. The valve was closed and the oil was pumped into the chamber until the platform rose. The Vernier valve was adjusted to the position of the platform.
3. The platform weight assembly was rotated while the measurement was taken. The weight on the platform, the True pressure calculated using $P_{\text{True}} = \text{Weight} / A_{\text{piston}}$, and pressure indicated by the pressure gauge (for the case of pressure gauge calibration) or the volts on the multimeter (for the case of pressure transducer calibration) were recorded.
4. Step 3 for each increment of 0.5 lb weight was repeated until the highest reading of the pressure gauge or the pressure transducer was reached (or a predetermined value).

1.6 Presentation of Raw Experimental Data

Table 2 Raw Data for 0 – 50 PSI Pressure Transducer $A=0.1 \text{ in}^2$

Weight (lb)	Generated True Pressure (psig)	Output voltage of pressure transducer	
		Volts (loading)	Volts (unloading)
0		1.32	1.36
0.5		1.90	1.93
1.0		2.45	2.45
1.5		2.94	2.95
2.0		3.45	3.44
2.5		3.98	3.94
3.0		4.45	4.44
3.5		4.96	4.95
4.0		5.45	5.45
4.5		5.95	5.94
5.0		6.45	6.44

Table 3 Raw Data for 0 – 250 PSI Pressure Gauge $A=0.02 \text{ in}^2$

Weight (lb)	Generated True Pressure (psig)	Output on Pressure Gauge	
		psig (loading)	psig (unloading)
0		0	0
0.5		25	25.2
1.0		50	50
1.5		75.1	75
2.0		100	100
2.5		125	125
3.0		150.5	150
3.5		175	175
4.0		200	200
4.5		225	225
5.0		250	250

- All of the raw data collected by class.

CHAPTER 2

ABILITY TO ANALYZE EXPERIMENTAL DATA

2.1 Detailed Computer Analysis of All Data

```
//W=0  
  
A1=0.1  
  
GTP=W/A1  
  
//V1=0  
//V2=0  
V=average(V1,V2)
```

Figure 3 Pressure Transducer

- Code for Pressure Transducer

```
//W=0  
  
A1=0.02  
  
GTP=W/A1  
  
//P1=0  
//P2=0  
P=average(P1,P2)
```

Figure 4 Pressure Gauge

- Code For Pressure Gauge

2.2 Presentation of Tables of Derived Results

Table 4 Pressure Transducer Results

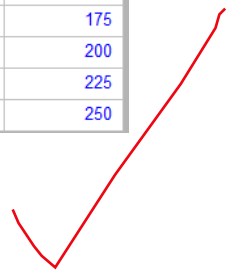
Table 1	1	2	3	4	5
1..11	W	GTP	V1	V2	V
Run 1	0	0	1.32	1.36	1.34
Run 2	0.5	5	1.9	1.93	1.915
Run 3	1	10	2.45	2.45	2.45
Run 4	1.5	15	2.94	2.95	2.945
Run 5	2	20	3.45	3.44	3.445
Run 6	2.5	25	3.98	3.94	3.96
Run 7	3	30	4.45	4.44	4.445
Run 8	3.5	35	4.96	4.95	4.955
Run 9	4	40	5.45	5.45	5.45
Run 10	4.5	45	5.95	5.94	5.945
Run 11	5	50	6.45	6.44	6.445

- GTP increases with weight

Table 5 Pressure Gauge Results

Table 1	1	2	3	4	5
1..11	W	GTP	P1	P2	P
Run 1	0	3.009E-36	0	0	0
Run 2	0.5	25	25	25.2	25.1
Run 3	1	50	50	50	50
Run 4	1.5	75	75.1	75	75.05
Run 5	2	100	100	100	100
Run 6	2.5	125	125	125	125
Run 7	3	150	150.5	150	150.3
Run 8	3.5	175	175	175	175
Run 9	4	200	200	200	200
Run 10	4.5	225	225	225	225
Run 11	5	250	250	250	250

- GTP increases with weight



CHAPTER 3

ABILITY TO INTERPRET EXPERIMENTAL DATA

3.1 Presentation of Graphs/Figures and Interpretation of Results Presented by each Graph/Figure

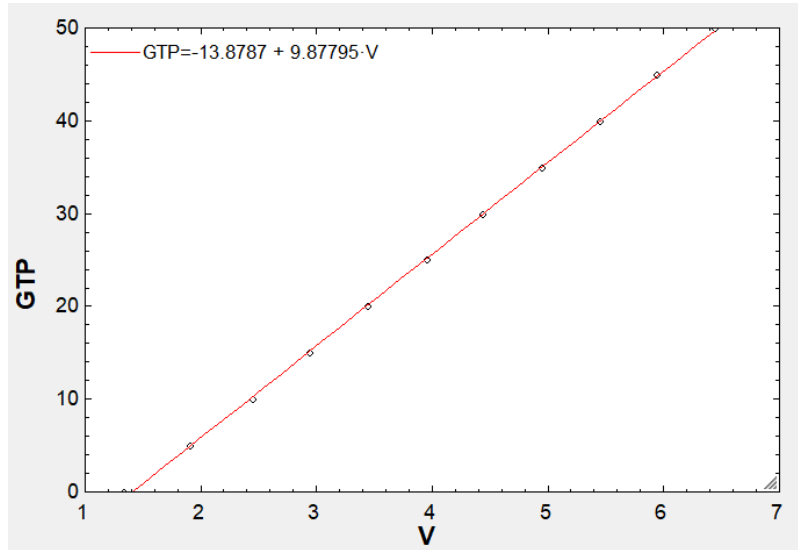


Figure 5 GTP V. V

- Generated True Pressure Vs. Average Output Voltage Pressure Transducer

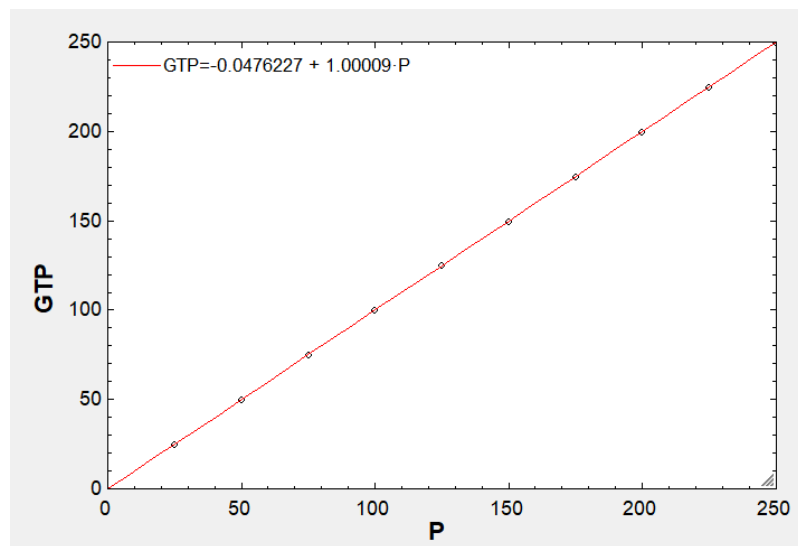


Figure 6 GTP V. P

- Generated True Pressure Vs. Average Output on the Pressure Gauge

missing discussion

3.2 Conclusions Based on each Objective and the Results

- Successfully learned how to perform a pressure gauge calibration using a dead weight tester.
- Successfully learned how to perform a pressure transducer calibration using a dead weight tester.
- Successfully used EES to determine the calibration equation using a curve fit and plot results.

3.3 Recommendations

Now that I have successfully learned how to perform a pressure gauge and transducer calibration using a dead weight tester as well as use statistical analysis in EES to determine the calibration equation using a curve fit. Experimental results can be improved by using skills learned during this lab to ensure that I am using the calibration device correctly and consistently.

BELOW AVERAGE

**MECHANICAL ENGINEERING DEPARTMENT
PRAIRIE VIEW A&M UNIVERSITY**



MCEG 3101 MEASUREMENT LABORATORY

Fall 2021 Section P01

LABORATORY REPORT ON

**“Pressure Transducer Calibration by a Dead Weight Tester and
Curve Fitting Technique”**

**Conducted on
October 18, 2021**

**Submitted by
Kiron Buie**

**On
October 24, 2021**

To

**Dr. Mingli Han
*Measurement Laboratory Instructor***

**MECHANICAL ENGINEERING DEPARTMENT
MEASUREMENT LABORATORY GRADING SHEET
FALL 2021 SECTION P01**

Title of Experiment: Pressure Transducer Calibration by a Dead Weight Tester and Curve Fitting Technique

Name: _____ Kiron Buie _____

Date Lab was Performed: __ 10/18/2021 _____

Report Due

Date: __ 10/25/2021 _____

<i>Ability to Conduct Experiments</i>	MAX	Your Score	Comments
Ability to demonstrate general lab safety (by your conduct and observations).	3	3	
Ability to follow the procedure and properly rephrasing the procedure to reflect what you did during the experiment.	7	7	
Ability to demonstrate knowledge of how equipment function, their limitations, and the uncertainty associated with reading the instruments.	5	5	
Ability to collect and record the raw data using appropriate units of measurement and identify the dependent and independent variables in the experiment.	5	0	
Total for Ability to Conduct Experiments	20		
Percentage for this Performance Criteria			
<i>Ability to Analyze and Interpret experimental Data in a Formal Report</i>			
Report format (Ability to properly format and present a technical report)	13	9	
Provides appropriate abstracts for the experimental report	5	1	
Ability to analyze the data using appropriate software to generate the required parameters using consistent units	27	27	
Ability to present the data (raw /derived) in tabular and graphical form to meet the objectives and to aid in interpretation.	14	12	
Ability to discuss the raw and derived data/graphs and assess the validity of the results in relation to the underlying theory and expected trends.	14	2	
Ability to draw appropriate and reasonable conclusions in relations to each of the experimental objectives. One conclusion statement for each objective.	7	2	
Total for Ability to Analyze and Interpret experimental Data	80		

TOTAL FOR THIS LAB		68	
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Letter of Transmittal

Kiron Buie
Mechanical Engineering Student
E M Norris Dr.
Prairie View , Texas 77445
Cell: 2148930148
E-mail: kbuie@student.pvamu.edu
Dr. Mingli Han
Measurement Laboratory Instructor
Prairie View A&M University
S. R. Collins Engineering Technology Building
Room 311

October 24, 2021

Dear Dr. Han:

The following pages are a detailed report for lab 3 of MCEG 3011 Measurement Laboratory, "Pressure Transducer Calibration by a Dead Weight Tester and Curve Fitting Technique". This report addresses performing a pressure gauge calibration using a dead weight tester, a pressure transducer calibration using a dead weight tester, and use EES to determine the calibration equation using a curve fit.. The lab was performed on October 18, 2021 and was submitted on October 24, 2021.

If you have any questions or concerns, please call or email me at any time.

Sincerely,

Kiron Buie

Enclosure: Lab Report

ABSTRACT

This summarizes the experiment, including results, (in a few paragraphs but not more than one page) so that the reader can decide whether he wants to go further. The abstract should contain

the following sub-sections, and the sub-section titles should be used explicitly in the abstracts:

1. The purpose of the experiment,
2. The brief description of method used
3. The significant results of the tests
4. The major conclusions drawn from the results.



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CHAPTER 1

ABILITY TO CONDUCT EXPERIMENTS

1.1 Objectives of the Experiment

1. To perform a pressure gauge calibration using a dead weight tester.
2. To perform a pressure transducer calibration using a dead weight tester
3. To use EES to determine the calibration equation using a curve fit.

1.2 Theory Associated with Experiment

Pascal's law says that pressure applied to an enclosed fluid will be transmitted without a change in magnitude to every point of the fluid and to the walls of the container. The pressure at any point in the fluid is equal in all directions.

1.3 Apparatus and Uncertainty in Reading Instruments

Dead weight tester, weights, voltmeter and pressure transducer.

Dead Weight Tester

The dead weight tester is a device used for balancing a fluid pressure with a known weight. It is used for static calibration of pressure gauges or transducer. Its schematic is shown in Figure 1. The chamber and cylinder are filled with a clean oil for pressure generation and transmission. The gauge or transducer to be

tested is installed and the piston inserted in the cylinder. The oil is pressurized by a pump. The pressure exerted on the fluid by the piston is transmitted to the gauge or transducer. This pressure is varied by

adding weights to the piston and pumping oil into the cylinder. The accuracy of dead weight tester is

limited by two factors:

Figure 1 The Dead Weight Tester

Table 1 Parts of the Deadweight Tester

- 1 Off set Pipe Assy 9 Air vent
- 2 Dead weight 10 Piston assembly
- 3 Platform 11 Vernier valve
- 4 Dead weight cylinder 12 Clevis pin
- 5 Body 13 Handle
- 6 Bolt 14 Union nut
- 7 Relief valve 15 Gauge pointer
- 8 Drip pan 16 Gauge

(1) The friction between the cylinder and the piston

The viscous friction between the piston and the cylinder in the axial direction is reduced by rotating the piston-weight assembly while the measurement is taken.

(2) The uncertainty in the area of the piston

The force of the weight acts not all at the area of the piston or the area of the cylinder. There is some of the effective area between these two which depends on the clearance spacing and the viscosity of the oil. The smaller the clearance, the more closely the effective area will approximate the cross-sectional area of the piston. It can show that percentage error due to clearance varies as:

Percent error DL

Where: ρ = density of oil

P = pressure on the cylinder

b = clearance spacing $2/(\rho c D D^2)$

η = viscosity of oil

c = cylinder diameter

= piston diameter pD

L = piston length

- Table 1 Parts of the Deadweight Tester
- 1 Off set Pipe Assy
 - 2 Dead weight 10 Piston assembly
 - 3 Platform 11 Vernier valve
 - 4 Dead weight cylinder 12 Clevis pin
 - 5 Body 13 Handle
 - 6 Bolt 14 Union nut
 - 7 Relief valve 15 Gauge pointer
 - 8 Drip pan 16 Gauge

(1) The friction between the cylinder and the piston

The viscous friction between the piston and the cylinder in the axial direction is reduced by rotating the piston-weight assembly while the measurement is taken.

(2) The uncertainty in the area of the piston

The force of the weight acts not all at the area of the piston or the area of the cylinder. There is some of the effective area between these two which depends on the clearance spacing and the viscosity of the oil. The smaller the clearance, the more closely the effective area will approximate the cross-sectional area of the piston. It can show that percentage error due to clearance varies as:

Percent error DL

$b P$

η

$\eta)(3$

$\sim$

Where: p = density of oil

P = pressure on the cylinder

b = clearance spacing $2/)(\eta pc DD \eta$

= viscosity of oil η

= cylinder diameter cD

= piston diameter pD

L = piston length

At high pressure there can be an elastic deformation of the cylinder which increases the clearance spacing

and thus increasing the error of the test. There are two kind of pistons used on the dead weight tester for

different pressure ranges of gauge or transducer. The cross section areas of pistons are different. The weights of the two pistons are the same.

1.4 Experimental Safety

Prior to starting the experiment, assume you are the safety inspector for this laboratory experiment and review

the following: By observing the experimental setup in detail and the surroundings, try to understand how the

system works, and list the following;

(a) All safety precautions that you think should be taken when running the Experiment.

(b) Any safety concerns you can point out and how you think the safety concern should be addressed.

1

2

1.5 Experimental Procedure

1. If the 0.5 lb piston is not already inserted in the cylinder, then insert it in the cylinder.

2. Close the valve and pump the oil into the chamber until the platform is raised up. Use the vernier valve to adjust position of the platform.
3. Rotate the platform weight assembly while the measurement is taken. Record both the weight on the platform, the True pressure calculated using $P_{\text{True}} = \text{Weight} / A_{\text{piston}}$, and pressure indicated by the pressure gauge (for the case of pressure gauge calibration) or the volts on the multimeter (for the case of pressure transducer calibration).
4. Repeat step 3 for each increment of 0.5 lb weight until the highest reading of the pressure gauge or the pressure transducer is reached (or a predetermined value).

1.6 Presentation of Raw Experimental Data



CHAPTER 2
ABILITY TO ANALYZE EXPERIMENTAL DATA

2.1 Detailed Computer Analysis of All Data

Figure 2.1

```
Equations Window
//W=0
A1=0.02
GTP = W/A1
//P1=0
//P2=0
P=average(P1,P2)
```

US Line: 1 Char: 6 Wrap: On Insert Caps Lock: Off SI C kPa kJ mass deg

Figure 2.2

```
Equations Window
//W = 0
A1= 0.1
GTP = W/A1
//V1=0
//V2=0
V=average(V1,V2)
```

US Line: 9 Char: 17 Wrap: On Insert Caps Lock: Off SI C kPa kJ r

2.2 Presentation of Tables of Derived Results

Table 2.1

Parametric Table					
Table 1					
1..11	1 W	2 GTP	3 V1	4 V2	5 V
Run 1	0	0	1.32	1.36	1.34
Run 2	0.5	5	1.9	1.93	1.915
Run 3	1	10	2.45	2.45	2.45
Run 4	1.5	15	2.94	2.95	2.945
Run 5	2	20	3.45	3.44	3.445
Run 6	2.5	25	3.98	3.94	3.96
Run 7	3	30	4.45	4.44	4.445
Run 8	3.5	35	4.96	4.95	4.955
Run 9	4	40	5.45	5.45	5.45
Run 10	4.5	45	5.95	5.94	5.945
Run 11	5	50	6.45	6.44	6.445

Table 2.2

Parametric Table					
Table 1					
1..11	1 W	2 GTP	3 P1	4 P2	5 P
Run 1	0	3.009E-36	0	0	0
Run 2	0.5	25	25	25.2	25.1
Run 3	1	50	50	50	50
Run 4	1.5	75	75.1	75	75.05
Run 5	2	100	100	100	100
Run 6	2.5	125	125	125	125
Run 7	3	150	150.5	150	150.3
Run 8	3.5	175	175	175	175
Run 9	4	200	200	200	200
Run 10	4.5	225	225	225	225
Run 11	5	250	250	250	250

CHAPTER 3
ABILITY TO INTERPRET EXPERIMENTAL DATA

3.1 Presentation of Graphs/Figures and Interpretation of Results Presented by
each Graph/Figure

Figure 3.3 3.1

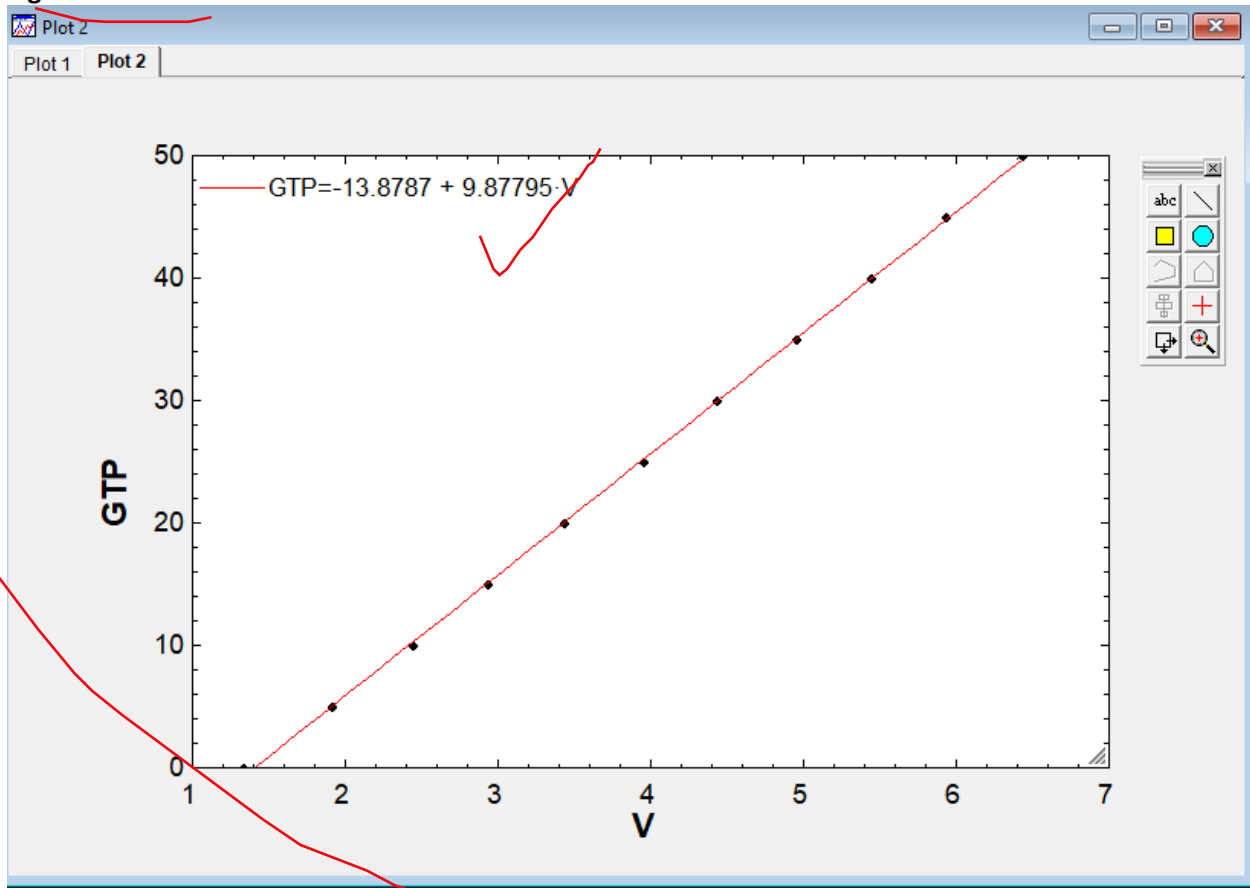
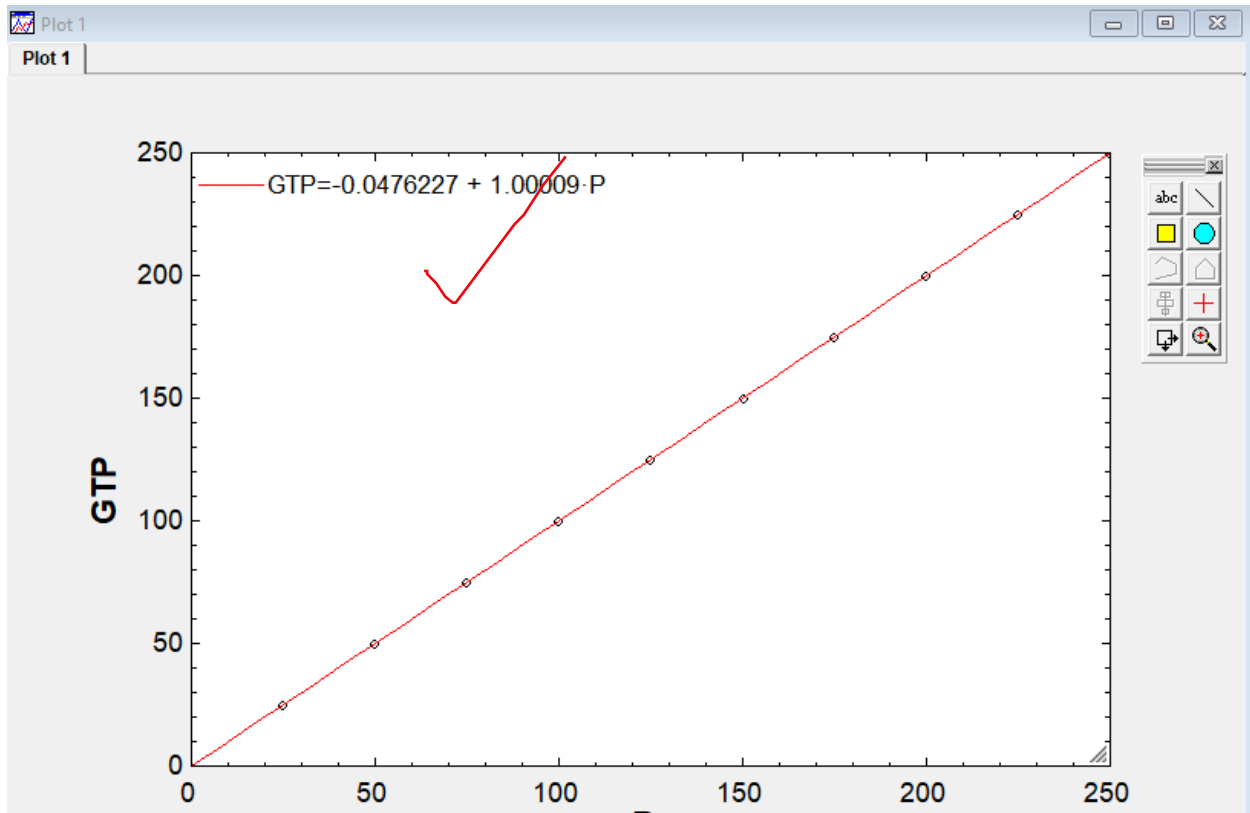


Figure 3.4



3.2 Conclusions Based on each Objective and the Results

3.3 Recommendations

I have no recommendations for this experiment. It went well.

**MEASUREMENT AND INSTRUMENTATION LABORATORY
FALL 2021**

LABORATORY REPORT # 4

TOPICS COVERED IN LABORATORY EXPERIMENT #4

**EXPERIMENT #4
STATISTICAL ANALYSIS OF EXPERIMENTAL DATA – LOCAL
GRAVITATIONAL ACCELERATION DETERMINATION BY A
SIMPLE PENDULUM**

The objectives of the experiment are to:

- 1. To determine the gravitational acceleration by a simple pendulum**
- 2. To use EES for statistical analysis of experimental data and for computing the uncertainty in the computed variables**
- 3. To present the computed physical quantity from measured data in the form of $g = g_m \pm \Delta g$**

**MEASUREMENT AND INSTRUMENTATION LABORATORY
FALL 2021**

LABORATORY HANDOUT FOR EXPERIMENT 4

**STATISTICAL ANALYSIS OF EXPERIMENTAL DATA – LOCAL
GRAVITATIONAL ACCELERATION DETERMINATION BY A
SIMPLE PENDULUM**

STATISTICAL ANALYSIS OF EXPERIMENTAL DATA – LOCAL GRAVITATIONAL ACCELERATION DETERMINATION BY A SIMPLE PENDULUM

Objective:

1. To determine the gravitational acceleration by a simple pendulum
2. To use EES for statistical analysis of experimental data and for computing the uncertainty in the computed variables
3. To present the computed physical quantity from measured data in the form of

$$g = g_m \pm \Delta g$$

Theory:

1. Error Computation

Errors or uncertainty involved in a result due to the uncertainties of the parameters involved in computations of measured values can be best obtained by using the Kline and McClintock formula also known as the Root-Sum-Square law. The formula is given as follows:

$$U_R = \left[\left(\frac{\partial R}{\partial X_1} U_{X_1} \right)^2 + \left(\frac{\partial R}{\partial X_2} U_{X_2} \right)^2 + \left(\frac{\partial R}{\partial X_3} U_{X_3} \right)^2 + \dots + \left(\frac{\partial R}{\partial X_N} U_{X_N} \right)^2 \right]^{\frac{1}{2}} \quad (1)$$

Where, R = the result

U_R = uncertainty in the result

X_i = parameters involved in computing the result

U_{X_i} = uncertainty in the parameters X_i

Example 4.1

A pressurized air tank is stored in a laboratory where the nominal ambient temperature is 27 °C. The air temperature is measured using a sensor with an uncertainty of 1 °C and the uncertainty in pressure measurement is 1%. Evaluate the uncertainty in determining the air density using the equation of state for an ideal gas.

The data reduction equation is

$$\rho = \frac{p}{RT} \quad (2)$$

The uncertainty expression becomes

$$U_\rho = \left[\left(\frac{\partial \rho}{\partial p} U_p \right)^2 + \left(\frac{\partial \rho}{\partial R} U_R \right)^2 + \left(\frac{\partial \rho}{\partial T} U_T \right)^2 \right]^{\frac{1}{2}} \quad (3)$$

The partial derivatives are

$$\frac{\partial \rho}{\partial p} = \frac{1}{RT} \quad (4)$$

$$\frac{\partial \rho}{\partial R} = -\frac{p}{R^2 T} \quad (5)$$

$$\frac{\partial \rho}{\partial T} = -\frac{p}{RT^2} \quad (6)$$

Substitution of the partial derivatives into (3) gives

$$U_{\rho} = \left[\left(\frac{1}{RT} U_p \right)^2 + \left(\frac{-p}{R^2 T} U_R \right)^2 + \left(\frac{-p}{RT^2} U_T \right)^2 \right]^{\frac{1}{2}} \quad (7)$$

Dividing the uncertainty expression (7) by the data reduction equation (2) gives

$$\frac{U_{\rho}}{\rho} = \left[\left(\frac{U_p}{p} \right)^2 + \left(\frac{U_R}{R} \right)^2 + \left(\frac{U_T}{T} \right)^2 \right]^{\frac{1}{2}} \quad (8)$$

Values for the variables are

$$T = 27^{\circ}\text{C} = 300\text{K}$$

$$U_T = 1^{\circ}\text{C} = 1\text{K}$$

$$\frac{U_p}{p} = 0.01$$

$$U_R = 0.0$$

The uncertainty in R , i.e. U_R is assumed negligible since the gas constant is available in reference sources with a great degree of certainty. Substitution of the numerical values in equation (8) gives the uncertainty in the air density

$$\frac{U_{\rho}}{\rho} = 0.011 = 1.1\%$$

The analysis presented for the above example problem shows the necessary steps in a general uncertainty analysis.

2. For a simple pendulum with small angular oscillation, neglecting friction, the frequency of oscillation f is given by

$$f = \frac{1}{2\pi} \sqrt{\frac{g}{L}} \quad (1)$$

Where g – local gravitational acceleration, m/s^2

L – length of the string (pendulum length), m

f – frequency of oscillation, cycles/s

if both side of equation 1 is squared, we get

$$f^2 = \frac{g}{4\pi^2} \frac{1}{L} \quad (2)$$

A graph of f^2 versus $1/L$ will be a straight line with a slope, S , given by

$$S = \frac{g}{4\pi^2} \quad (3)$$

from which g can be computed.

Statistical Analysis

The Mean: The mean x_m , of a set of n data in which each data is represented by x_i ($i=1$ to n) is given by

$$x_m = \frac{1}{n} \sum_{i=1}^n x_i \quad (4)$$

The Deviation: The deviation d_i of a set of n data in which each data is represented by x_i ($i=1$ to n) is given by

$$d_i = |x_i - x_m| \quad (5)$$

Note that the average of the deviations of all the data is zero since the sum of the deviation is zero.

The Mean Deviation: The average of the absolute values of the deviations is however not zero, and is given by

$$\left| \bar{d}_i \right| = \frac{1}{n} \sum |x_i - x_m| \quad (6)$$

The Standard Deviation: The standard deviation is also known as the root mean square deviation. It is one of the most important statistical parameters that is used to ascertain the accuracy as well as the confidence one will have in the value of the measured data. The standard deviation for a very large set of data is given by

$$\sigma = \left[\frac{1}{n} \sum_{i=1}^n (x_i - x_m)^2 \right]^{1/2} \quad (7)$$

When the number of data is not large (greater than 20 for example), the sample standard deviation is given by

$$\sigma = \left[\frac{\sum (x_i - x_m)^2}{n-1} \right]^{1/2} \quad (8)$$

Apparatus:

String, weight, straight rule, stop watch

Procedure:

Note: Each group perform the experiment at one nominal pendulum string length, L_{Nominal} . Each member in the group will then measure the actual pendulum length and then record one set of data.

1. Set the pendulum length to the approximate nominal length prescribed for the group
2. Measure the actual pendulum length in (cm).
3. Swing the pendulum at a small angle from the vertical and record the time required for 10 cycles of oscillations. Note that the count should start from zero (0) at the time the stop watch is started.
4. Record the data on the raw data sheet.

Laboratory Report:

1. Set your Units to SI in EES
2. For each nominal length, input the actual lengths, L_1 , L_2 , L_3 , L_4 and L_5 in your EES program and use the average function to calculate the average length, L .
3. For each nominal length, input the times for 10 oscillations, T_1 , T_2 , T_3 , T_4 and T_5 in your EES program and use the average function to calculate the average time, T for 10 oscillations
4. Calculate the frequency, f , as $f=N/T$ where $N= 10$ oscillations.
5. Set $Y=f^2$ and $X=1/L$

6. For the data for the pendulum lengths measured, compute the sum of absolute deviations, d_L , the mean deviation, d_{mL} , and the standard deviation σ_L for the data at each nominal pendulum length.
7. For the data for the time, T , for 10 oscillations measured, compute the sum of absolute deviations, d_T , the mean deviation, d_{mT} , and the standard deviation σ_T for the data at each nominal pendulum length.
8. Run your program to ensure it works properly
9. Create a Table in EES with the columns $L_1, L_2, L_3, L_4, L_5, T_1, T_2, T_3, T_4, T_5, L, T, f, X, Y, d_L, d_{mL}, \sigma_L, d_T, d_{mT},$ and σ_T ,
10. Transfer the raw data into the EES table you have created.
11. Use the Solve table command to solve the table after commenting out the raw data variables in the program.
12. Plot Y versus X . This should come out as a straight line
13. Use EES to fit the best straight line through the points and note the statistics for the fit.
14. Plot the equation of the straight line on the plot and indicate the slope
15. Input the value of the slope, S , in your EES Equation and use Equation (3) to compute the value of g .
16. Using the standard error of S as the uncertainty in the experimental data, use EES to compute the uncertainty in the computed value of g .

Formal Laboratory Report

1. Present the information in a well written standard laboratory report following the detailed report format provided to you and discussed in class.
2. Completely discuss and interpret your results including all graphs and computed results as required.

Raw Experimental Data

#	Name of Student	Length of Pendulum, L (cm)	Time for N=10 Oscillations (s)
Group 1		$L_{\text{nominal}} = 85 \text{ cm}$	
1		$L_1 = 82.5$	$T_1 = 18.17$
2		$L_2 = 82.6$	$T_2 = 18.15$
3		$L_3 = 82.3$	$T_3 = 18.11$
4		$L_4 = 82.4$	$T_4 = 18.13$
5		$L_5 = 83.3$	$T_5 = 18.12$
Group 2		$L_{\text{nominal}} = 75 \text{ cm}$	
6		$L_1 = 74.3$	$T_1 = 17.07$
7		$L_2 = 74.2$	$T_2 = 17.17$
8		$L_3 = 73.3$	$T_3 = 17.22$
9		$L_4 = 74.6$	$T_4 = 17.17$
10		$L_5 = 73.5$	$T_5 = 17.18$
Group 3		$L_{\text{nominal}} = 65$	
11		$L_1 = 66$	$T_1 = 16.21$
12		$L_2 = 65.5$	$T_2 = 15.73$
13		$L_3 = 65.9$	$T_3 = 15.33$
14		$L_4 = 65.7$	$T_4 = 16.15$
15		$L_5 = 65.5$	$T_5 = 16.03$
Group 4		$L_{\text{nominal}} = 55 \text{ cm}$	
16		$L_1 = 55.4$	$T_1 = 15.09$
17		$L_2 = 54.5$	$T_2 = 14.87$
18		$L_3 = 55$	$T_3 = 14.79$
19		$L_4 = 55$	$T_4 = 14.61$
20		$L_5 = 55.2$	$T_5 = 15.20$
Group 5		$L_{\text{nominal}} = 45 \text{ cm}$	
21		$L_1 = 45.2$	$T_1 = 13.59$
22		$L_2 = 44.5$	$T_2 = 14.90$
23		$L_3 = 45.1$	$T_3 = 13.86$
24		$L_4 = 45.2$	$T_4 = 14.09$
25		$L_5 = 45.1$	$T_5 = 13.94$
GROUP 6		$L_{\text{nominal}} = 35 \text{ cm}$	
26		$L_1 = 38.3$	$T_1 = 13.31$
27		$L_2 = 38.5$	$T_2 = 12.75$
28		$L_3 = 38.1$	$T_3 = 11.85$
29		$L_4 = 38.2$	$T_4 = 13.23$
30		$L_5 = 37.5$	$T_5 = 12.40$

ABOVE AVERAGE

PRAIRIE VIEW A&M UNIVERSITY



MCEG 3101 MEASUREMENT LABORATORY

Fall 2021 Section P01

LABORATORY REPORT ON

**“Statistical Analysis of Experimental Data – Local Gravitational
Acceleration Determination by a Simple Pendulum”**

**Conducted on
October 26, 2021**

**Submitted by
Malaika Lee**

**On
November 2, 2021**

To

**Dr. Mingli Han
*Measurement Laboratory Instructor***

MECHANICAL ENGINEERING DEPARTMENT
MEASUREMENT LABORATORY GRADING SHEET
FALL 2021 SECTION P01

Title of Experiment: _____

Name: _____

Date Lab was Performed: _____ Report Due Date: _____

<i>Ability to Conduct Experiments</i>	MAX	Your Score	Comments
Ability to demonstrate general lab safety (by your conduct and observations).	3	3	
Ability to follow the procedure and properly rephrasing the procedure to reflect what you did during the experiment.	7	7	
Ability to demonstrate knowledge of how equipment function, their limitations, and the uncertainty associated with reading the instruments.	5	5	
Ability to collect and record the raw data using appropriate units of measurement and identify the dependent and independent variables in the experiment.	5	5	
Total for Ability to Conduct Experiments	20		
Percentage for this Performance Criteria			
<i>Ability to Analyze and Interpret experimental Data in a Formal Report</i>			
Report format (Ability to properly format and present a technical report)	13	11	
Provides appropriate abstracts for the experimental report	5	5	
Ability to analyze the data using appropriate software to generate the required parameters using consistent units	27	23	
Ability to present the data (raw /derived) in tabular and graphical form to meet the objectives and to aid in interpretation.	14	14	
Ability to discuss the raw and derived data/graphs and assess the validity of the results in relation to the underlying theory and expected trends.	14	14	
Ability to draw appropriate and reasonable conclusions in relations to each of the experimental objectives. One conclusion statement for each objective.	7	5	
Total for Ability to Analyze and Interpret experimental Data	80		
TOTAL FOR THIS LAB		92	

Malaika lee
Mechanical Engineering Student
914 Linn Street
Waco, Texas 76704
Cell: 254-717-9889
E-mail: mlee27@pvamu.edu

Dr. Mingli Han
Measurement Laboratory Instructor
Prairie View A&M University
S. R. Collins Engineering Technology Building
Room 311

November 2, 2021

Dear Dr. Han:

The following pages are a detailed report for lab 4 of MCEG 3011 Measurement Laboratory, "Statistical Analysis of Experimental Data – Local Gravitational Acceleration Determination by a Simple Pendulum". This report addresses the use of pendulums to determine gravitational acceleration. The lab was performed on October 26, 2021 and was submitted on November 2, 2021.

If you have any questions or concerns, please call or email me at any time.

Sincerely,

Malaika lee
Enclosure: Lab Report

ABSTRACT

The purpose of this experiment was to introduce the use of simple pendulums to calculate the gravitational acceleration constant. Also, the lab introduced the use of EES to calculate uncertainty values and statistically analyze variables.

During the experiment, the methods that were used consisted of gathering data using the pendulum at varying nominal lengths and using EES to statistically analyze the data points. Formulas were used to derive certain necessary parameters that existed within our data points.

From the lab, we can conclude that the data collected from the students were precise and could be properly used to calculate the gravitational acceleration constant.

It can be concluded that the gravitational acceleration is around 9.58. This value was measured after experimentation and calculations of the data points.

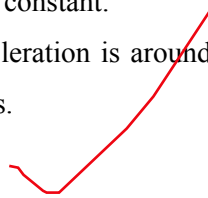


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CHAPTER 1

ABILITY TO CONDUCT EXPERIMENTS

1.1 Objectives

1. To determine the gravitational acceleration by a simple pendulum
2. To use EES for statistical analysis of experimental data and for computing the uncertainty in the computed variables
3. To present the computed physical quantity from measured data in the form of

$$g = g_m \pm \Delta g$$

1.2 Theory Associated with Experiment

Error Computation

Errors or uncertainty involved in a result due to the uncertainties of the parameters involved in computations of measured values can be best obtained by using the Kline and McClintock formula also known as the Root-Sum-Square law. The formula is given as follows:

$$U_R = \left[\left(\frac{\partial R}{\partial X_1} U_{X_1} \right)^2 + \left(\frac{\partial R}{\partial X_2} U_{X_2} \right)^2 + \left(\frac{\partial R}{\partial X_3} U_{X_3} \right)^2 + \dots + \left(\frac{\partial R}{\partial X_N} U_{X_N} \right)^2 \right]^{\frac{1}{2}} \quad (1)$$

Where,

- R = The result
 U_R = Uncertainty of the result
 X_i = Parameters involved in computing the result
 U_{Xi} = Uncertainty in the parameters X_i

Experiment

For a simple pendulum with small angular oscillation, neglecting friction, the frequency of oscillation f is given by

$$f = \frac{1}{2\pi} \sqrt{\frac{g}{L}} \quad (9)$$

Where,

- g = local gravitational acceleration, m/s²
 L = length of the string (pendulum length), m
 f = Frequency of oscillation, cycles/s

if both side of equation (9) is squared, we get

$$f^2 = \frac{g}{4\pi^2} \frac{1}{L} \quad (10)$$

A graph of f^2 versus $1/L$ will be a straight line with a slope, S , given by

$$S = \frac{g}{4\pi^2} \quad (11)$$

from which g can be computed.

Statistical Analysis

The Mean: The mean x_m , of a set of n data in which each data is represented by x_i ($i=1$ to n) is given by

$$x_m = \frac{1}{n} \sum_{i=1}^n x_i \quad (12)$$

The Deviation: The deviation d_i of a set of n data in which each data is represented by x_i ($i=1$ to n) is given by

$$d_i = |x_i - x_m| \quad (13)$$

Note that the average of the deviations of all the data is zero since the sum of the deviation is zero.

The Mean Deviation: The average of the absolute values of the deviations is however not zero, and is given by

$$\left| \bar{d}_i \right| = \frac{1}{n} \sum |x_i - x_m| \quad (14)$$

The Standard Deviation: The standard deviation is also known as the root mean square deviation. It is one of the most important statistical parameters that is used to ascertain the accuracy as well as the confidence one will have in the value of the measured data. The standard deviation for a very large set of data is given by

$$\sigma = \left[\frac{1}{n} \sum_{i=1}^n (x_i - x_m)^2 \right]^{1/2} \quad (15)$$

When the number of data is not large (greater than 20 for example), the sample standard deviation is given by

$$\sigma = \left[\frac{\sum (x_i - x_m)^2}{n-1} \right]^{1/2} \quad (16)$$

1.3 Apparatus and Uncertainty in Reading Instruments

String, weight, straight rule, stop watch

1.4 Experimental Safety

I did not observe any safety concerns that should be addressed for the experiment.

1.5 Experimental Procedure

Note: Each group perform the experiment at one nominal pendulum string length, L_{Nominal} . Each member in the group will then measure the actual pendulum length and then record one set of data

- 1) If Set the pendulum length to the approximate nominal length prescribed for the group
- 2) Measure the actual pendulum length in (cm).
- 3) Swing the pendulum at a small angle from the vertical and record the time required for 10 cycles of oscillations. Note that the count should start from zero (0) at the time the stop watch is started.
- 4) Record the data on the raw data sheet.

1.6 Presentation of Raw Experimental Data

Table 1.1 Raw data

Norminal Length	Measured Length (cm)		Time for 10 oscillations (sec)	
85cm	L1	85.4	T1	17.79
	L2	85.2	T2	17.97
	L3	82	T3	17.96
	L4	82.5	T4	17.96
	L5	82	T5	17.93
75cm	L1	75.5	T1	16.56
	L2	75.3	T2	16.77
	L3	75.1	T3	16.85
	L4	75.5	T4	16.83
	L5	75.4	T5	16.71
65cm	L1	64.5	T1	15.9
	L2	64.6	T2	15.74
	L3	63	T3	15.68
	L4	65	T4	15.8
	L5	64.8	T5	15.76
55cm	L1	54.7	T1	14.65
	L2	54.8	T2	14.38
	L3	54.6	T3	14.43
	L4	54	T4	14.41
	L5	53.8	T5	14.45
45cm	L1	45.56	T1	13.21
	L2	46	T2	13.22
	L3	46	T3	13.19
	L4	45.58	T4	13.71
	L5	45.59	T5	13.32
35cm	L1	34.7	T1	11.77
	L2	34.8	T2	11.76
	L3	34.9	T3	11.74
	L4	34.7	T4	11.78
	L5	34.6	T5	11.76

CHAPTER 2

ABILITY TO ANALYZE EXPERIMENTAL DATA

2.1 Detailed Computer Analysis of All Data

Table 2.1 Equation Window

```
x=y Equations Window
//L1 = 0
//L2 = 0
//L3 = 0
//L4 = 0
//L5 = 0

//T1 = 0
//T2 = 0
//T3 = 0
//T4 = 0
//T5 = 0

{L = average(L1,L2,L3,L4,L5)/100
T = average(T1,T2,T3,T4,T5)

x = 1/L
N = 10
f = N/T
y = f^2

dL= stddev(L1,L2,L3,L4,L5)
dml = dL/N
dT= stddev( T1,T2,T3,T4,T5)
dmT = dT/N}

S = .242659
g = 4*pi^2* S
```

Table 2.1 shows the formatted equation window in EES.

2.2 Presentation of Tables of Derived Results

Table 2.2 Solution Window

Solution		
Uncertainty Results		
Unit Settings: SI C kPa kJ mass deg		
Variable±Uncertainty	Partial derivative	% of uncertainty
$g = 9.58 \pm 0.1587$		
$S = 0.2427 \pm 0.004019$	$\partial g / \partial S = 39.48$	100.00 %
No unit problems were detected.		
Compilation time = 31 ms Calculation time = 99.53 s		

Table 2.2 shows the uncertainty results for the calculated gravitational constant and the slope of the X-Y plot.

Table 2.3 Parametric Table

Parametric Table										
Table 1 Table 2										
1.6	L1	L2	L3	L4	L5	T1	T2	T3	T4	T5
Run 1	85.4	85.2	82	82.5	82	17.79	17.97	17.96	17.96	17.93
Run 2	75.5	75.3	75.1	75.5	75.4	16.56	16.77	16.85	16.83	16.71
Run 3	64.5	64.6	63	65	64.8	15.9	15.74	15.68	15.8	15.76
Run 4	54.7	54.8	54.6	54	53.8	14.65	14.38	14.43	14.41	14.45
Run 5	45.56	46	46	45.58	45.59	13.21	13.22	13.19	13.71	13.32

11	dL	12	dml	13	dmT	14	dT	15	L	16	T	17	x	18	y	19	f	20	N
	0.173		0.173		0.00753		0.0753		0.8342		17.92		1.199		0.3113		0.558		10
	0.1673		0.01673		0.01165		0.1165		0.7536		16.74		1.327		0.3567		0.5972		10
	0.795		0.0795		0.008173		0.08173		0.6438		15.78		1.553		0.4018		0.6339		10
	0.4494		0.04494		0.01071		0.1071		0.5438		14.46		1.839		0.478		0.6914		10
	0.2321		0.02321		0.02183		0.2183		0.4575		13.33		2.185		0.5528		0.7502		10
	0.114		0.0114		0.001483		0.01483		0.3474		11.76		2.679		0.7228		0.8502		10

Table 2.3 shows in detail the given values for the length of the strings and times, and the calculated values.

CHAPTER 3

ABILITY TO INTERPRET EXPERIMENTAL DATA

3.1 Presentation of Graphs/Figures and Interpretation of Results Presented by each Graph/Figure

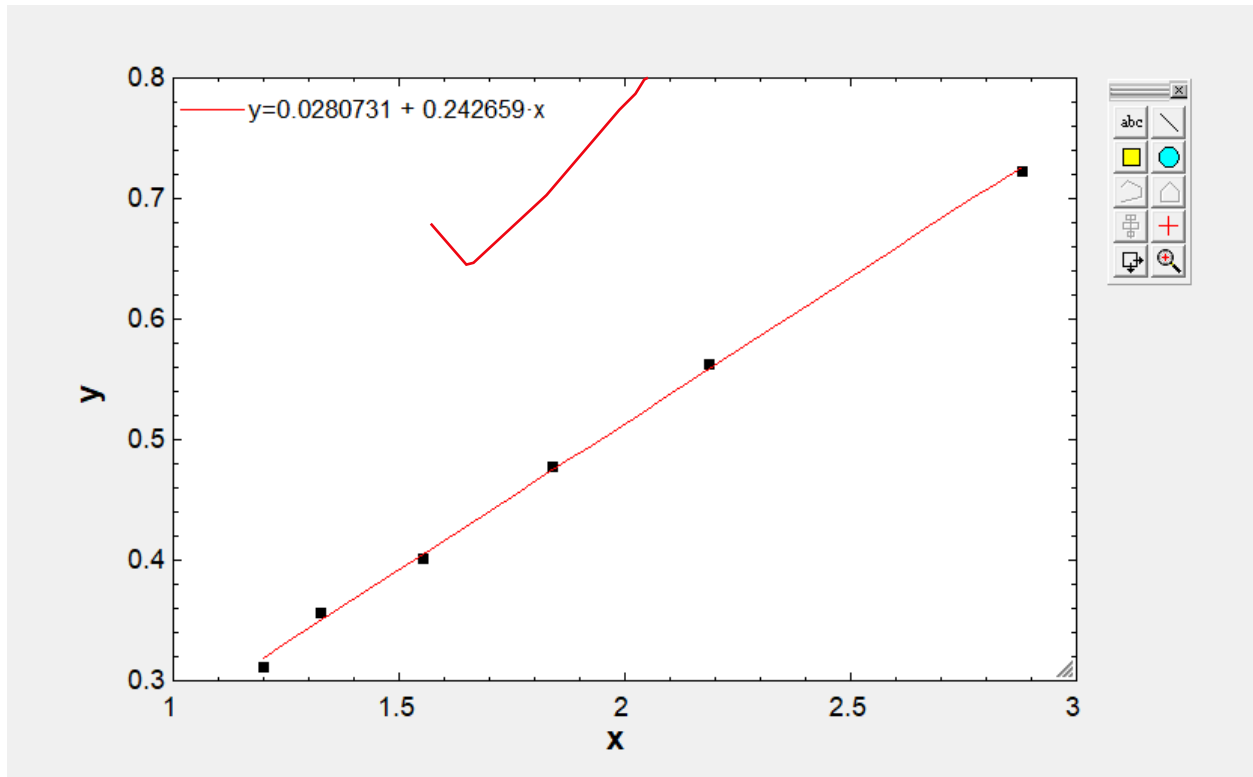


Figure 3.1 X-Y Plot

As graph 3.1 depicts the plot of the X-Y values that were calculated from the string length and time valued determined through experimentation. The slope of the graph, S, helped determine our gravitational constant.

3.2 Conclusions Based on each Objective and the Results

In conclusion, this lab introduced the use of a simple pendulum to calculate the gravitational constant. From experimentation and further analysis of collected data, it can be concluded that the gravitational constant is around 9.58.

3.3?

AVERAGE

**MECHANICAL ENGINEERING DEPARTMENT
PRAIRIE VIEW A&M UNIVERSITY**



MCEG 3101 MEASUREMENT LABORATORY

Fall 2021 Section P01

LABORATORY REPORT ON

“Final Gravity measurement by Simple Pendulum”

**Conducted on
October 26, 2021**

**Submitted by
Kiron Buie**

**On
November 2, 2021**

To

**Dr. Mingli Han
*Measurement Laboratory Instructor***

**MECHANICAL ENGINEERING DEPARTMENT
MEASUREMENT LABORATORY GRADING SHEET
FALL 2021 SECTION P01**

Title of Experiment: Pressure Transducer Calibration by a Dead Weight Tester and Curve Fitting Technique

Name: _____ Kiron Buie _____

Date Lab was Performed: __ 10/26/2021 _____

Report Due

Date: __ 11/2/2021 _____

<i>Ability to Conduct Experiments</i>	MAX	Your Score	Comments
Ability to demonstrate general lab safety (by your conduct and observations).	3	3	
Ability to follow the procedure and properly rephrasing the procedure to reflect what you did during the experiment.	7	7	
Ability to demonstrate knowledge of how equipment function, their limitations, and the uncertainty associated with reading the instruments.	5	4	
Ability to collect and record the raw data using appropriate units of measurement and identify the dependent and independent variables in the experiment.	5	5	
Total for Ability to Conduct Experiments	20		
Percentage for this Performance Criteria			
<i>Ability to Analyze and Interpret experimental Data in a Formal Report</i>			
Report format (Ability to properly format and present a technical report)	13	9	
Provides appropriate abstracts for the experimental report	5	1	
Ability to analyze the data using appropriate software to generate the required parameters using consistent units	27	17	
Ability to present the data (raw /derived) in tabular and graphical form to meet the objectives and to aid in interpretation.	14	12	
Ability to discuss the raw and derived data/graphs and assess the validity of the results in relation to the underlying theory and expected trends.	14	10	
Ability to draw appropriate and reasonable conclusions in relations to each of the experimental objectives. One conclusion statement for each objective.	7	7	
Total for Ability to Analyze and Interpret experimental Data	80		

TOTAL FOR THIS LAB		75	
---------------------------	--	-----------	--

Letter of Transmittal

Kiron Buie
Mechanical Engineering Student
E M Norris Dr.
Prairie View , Texas 77445
Cell: 2148930148
E-mail: kbuie@student.pvamu.edu
Dr. Mingli Han
Measurement Laboratory Instructor
Prairie View A&M University
S. R. Collins Engineering Technology Building
Room 311

November 2, 2021

Dear Dr. Han:

The following pages are a detailed report for lab 4 of MCEG 3011 Measurement Laboratory, "Final Gravity measurement by Simple Pendulum". This report addresses the gravitational acceleration by a simple pendulum, to use EES for statistical analysis of experimental data and for computing the uncertainty in the computed variables , and to present the computed physical quantity from measured data. The lab was performed on October 26, 2021 and was submitted on November 2, 2021. If you have any questions or concerns, please call or email me at any time.

Sincerely,

Kiron Buie

Enclosure: Lab Report

ABSTRACT

This summarizes the experiment, including results, (in a few paragraphs but not more than one page) so that the reader can decide whether he wants to go further. The abstract should contain

the following sub-sections, and the sub-section titles should be used explicitly in the abstracts:

1. The purpose of the experiment,
2. The brief description of method used
3. The significant results of the tests
4. The major conclusions drawn from the results.



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should be on a separate page

CHAPTER 1

ABILITY TO CONDUCT EXPERIMENTS

1.1 Objectives of the Experiment

1. To determine the gravitational acceleration by a simple pendulum (<https://www.youtube.com/watch?v=z6ZdhP167RY>)
2. To use EES for statistical analysis of experimental data and for computing the uncertainty in the computed variables
3. To present the computed physical quantity from measured data in the form of

1.2 Theory Associated with Experiment

1. Error Computation

Errors or uncertainty involved in a result due to the uncertainties of the parameters involved in computations of measured values can be best obtained by using the Kline and McClintock formula also known as the Root-Sum-Square law. The formula is given as follows:

1.3 Apparatus and Uncertainty in Reading Instruments

String, weight, straight rule, stop watch

1.4 Experimental Safety

Prior to starting the experiment, assume you are the safety inspector for this laboratory experiment and review

the following: By observing the experimental setup in detail and the surroundings, try to understand how the

system works, and list the following;

- (a) All safety precautions that you think should be taken when running the Experiment.
- (b) Any safety concerns you can point out and how you think the safety concern should be addressed.

1

2

1.5 Experimental Procedure

1. Set the pendulum length to the approximate nominal length prescribed for the group
2. Measure the actual pendulum length in (cm).
3. Swing the pendulum at a small angle from the vertical and record the time required for 10 cycles of oscillations. Note that the count should start from zero (0) at the time the stop watch is started.
4. Record the data on the raw data sheet.

1.6 Presentation of Raw Experimental Data

Table 1.1 Raw Data

Normal Length	Measured Length (cm)		Time for 10 oscillations (sec)	
85cm	L1	85.4	T1	17.79
	L2	85.2	T2	17.97
	L3	82	T3	17.96
	L4	82.5	T4	17.96
	L5	82	T5	17.93
75cm	L1	75.5	T1	16.56
	L2	75.3	T2	16.77
	L3	75.1	T3	16.85
	L4	75.5	T4	16.83
	L5	75.4	T5	16.71
65cm	L1	64.5	T1	15.9
	L2	64.6	T2	15.74
	L3	63	T3	15.68
	L4	65	T4	15.8
	L5	64.8	T5	15.76
55cm	L1	54.7	T1	14.65
	L2	54.8	T2	14.38
	L3	54.6	T3	14.43
	L4	54	T4	14.41
	L5	53.8	T5	14.45
45cm	L1	45.56	T1	13.21
	L2	46	T2	13.22
	L3	46	T3	13.19
	L4	45.58	T4	13.71
	L5	45.59	T5	13.32
35cm	L1	34.7	T1	11.77
	L2	34.8	T2	11.76
	L3	34.9	T3	11.74
	L4	34.7	T4	11.78
	L5	34.6	T5	11.76

CHAPTER 2

ABILITY TO ANALYZE EXPERIMENTAL DATA

2.1 Detailed Computer Analysis of All Data

Figure 2.1 Equation Window

Equations Window

$L1=0$
 $L2=0$
 $L3=0$
 $L4=0$
 $L5=0$
 $T1=0$
 $T2=0$
 $T3=0$
 $T4=0$
 $T5=0$

$L = \text{average}(L1, L2, L3, L4, L5) / 100$
 $t = \text{average}(T1, T2, T3, T4, T5)$

$x = 1/L$
 $N = 10$
 $f = NT$
 $y = P2$

$S = 0.2426$
 $g = 4 \pi^2 S$

missing the standard deviation for L and T

$\sigma_L \quad \sigma_T ?$

Update Menu
☐ Highlight vars used once
 Main Program
 g
 S

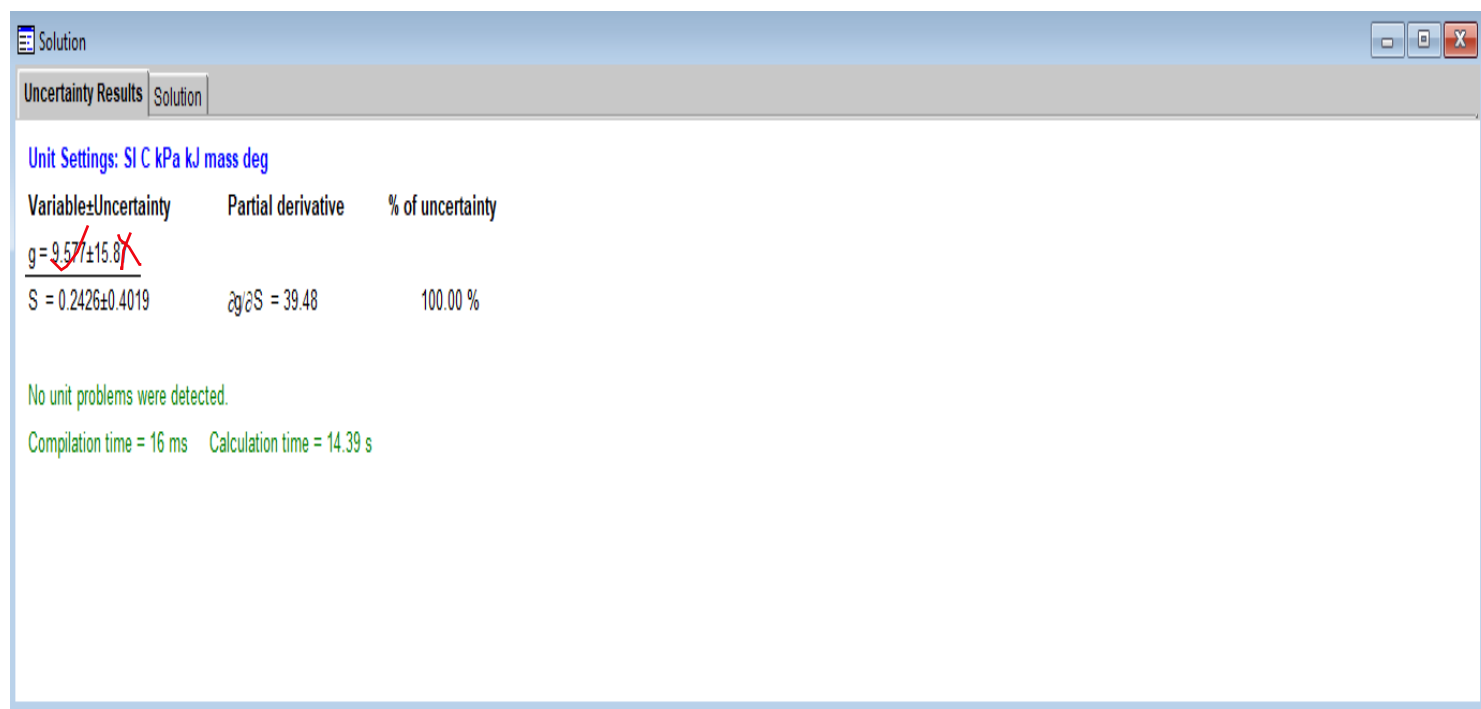
US Line: 22 Chan: 1 Wrap: On Insert Caps Lock: Off SI C kPa kJ mass deg Warnings: On Unit Chk: On Complex: Off Syntax Highlight: Off

2.2 Presentation of Tables of Derived Results

Table 2.2 Table Values

Parametric Table														
Table 1														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	L1	L2	L3	L4	L5	T1	T2	T3	T4	T5	L	t	x	y
Run 1	85.4	85.2	82	82.5	82	17.79	17.97	17.96	17.96	17.93				
Run 2	75.5	75.3	75.1	75.5	75.4	16.56	16.77	16.85	16.83	16.71	0.7536	16.74	1.327	0.3567
Run 3	64.5	64.6	63	65	64.8	15.9	15.74	15.68	15.8	15.76	0.6438	15.78	1.553	0.4018
Run 4	54.7	54.8	54.6	54	53.8	14.65	14.38	14.43	14.41	14.45	0.5438	14.46	1.839	0.478
Run 5	45.56	46	46	45.58	45.59	13.21	13.22	13.19	13.71	13.32	0.4575	13.33	2.186	0.5628
Run 6	34.7	34.8	34.9	34.7	34.6	11.77	11.76	11.74	11.78	11.76	0.3474	11.76	2.879	0.7228

Figure 2.2 Results

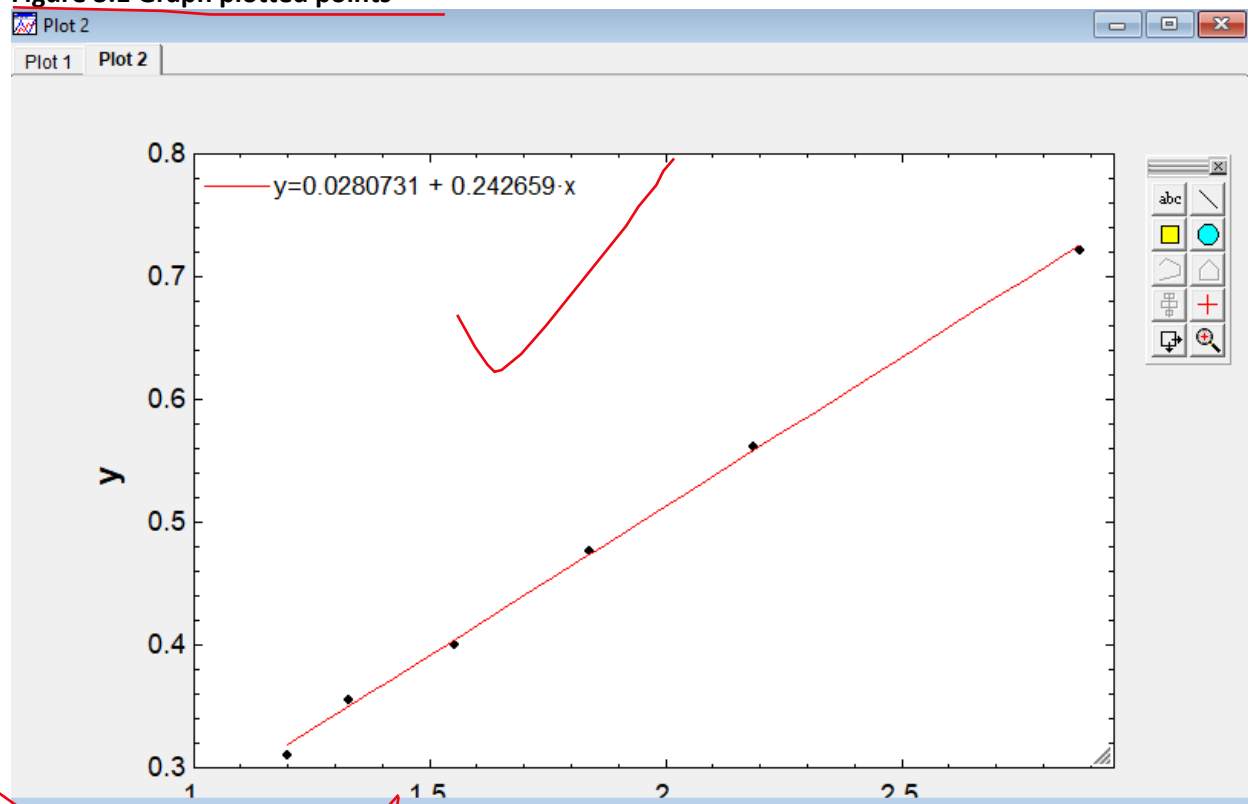


CHAPTER 3

ABILITY TO INTERPRET EXPERIMENTAL DATA

3.1 Presentation of Graphs/Figures and Interpretation of Results Presented by each Graph/Figure

Figure 3.1 Graph plotted points



3.2 Conclusions Based on each Objective and the Results

The Variable and uncertainty number equated to 9.577 which is close to 9.81 which is the gravitational constant, meaning the calculations were accurate

3.3 Recommendations

There are no recommendations as far as the experiment, the software did everything.

REFERENCES

This section should contain all books, and materials consulted in the process of performing the experiment, during the analysis, and discussion phases of the report. All reference materials should be directly referenced in the report. The ASME standard for listing references is recommended. Also consult the Senior Project manual on the proper way to cite and list references.

6

APPENDICES

The appendix should include supporting material that will overburden the rest of the report. It is the place for lengthy or bulky materials such as the calculations for all the other data points, EES programs, detailed

descriptions of test methods, listing of computer programs.

BELOW AVERAGE

**MECHANICAL ENGINEERING DEPARTMENT
PRAIRIE VIEW A&M UNIVERSITY**



MCEG 3101 MEASUREMENT LABORATORY

Fall 2021 Section P01

LABORATORY REPORT ON

“Gravity Measurement by Simple Pendulum”

**Conducted on
October 19, 2021**

**Submitted by
Devan Mitchell
On
November 11, 2021**

**To
Dr. Mingli Han**

**MECHANICAL ENGINEERING DEPARTMENT
MEASUREMENT LABORATORY GRADING SHEET**

FALL 2021 SECTION P01

Title of Experiment: _____

Name: _____

Date Lab was Performed: _____ Report Due Date: _____

<i>Ability to Conduct Experiments</i>	MAX	Your Score	Comments
Ability to demonstrate general lab safety (by your conduct and observations).	3	0	
Ability to follow the procedure and properly rephrasing the procedure to reflect what you did during the experiment.	7	7	
Ability to demonstrate knowledge of how equipment function, their limitations, and the uncertainty associated with reading the instruments.	5	5	
Ability to collect and record the raw data using appropriate units of measurement and identify the dependent and independent variables in the experiment.	5	2	
Total for Ability to Conduct Experiments	20		
Percentage for this Performance Criteria			
<i>Ability to Analyze and Interpret experimental Data in a Formal Report</i>			
Report format (Ability to properly format and present a technical report)	13	7	
Provides appropriate abstracts for the experimental report	5	4	
Ability to analyze the data using appropriate software to generate the required parameters using consistent units	27	18	

Ability to present the data (raw /derived) in tabular and graphical form to meet the objectives and to aid in interpretation.	14	10	
Ability to discuss the raw and derived data/graphs and assess the validity of the results in relation to the underlying theory and expected trends.	14	2	
Ability to draw appropriate and reasonable conclusions in relations to each of the experimental objectives. One conclusion statement for each objective.	7	0	
Total for Ability to Analyze and Interpret experimental Data	80		
TOTAL FOR THIS LAB		55	

Devan Mitchell
Mechanical Engineering Student
12500 Barker Cypress
Cypress, Texas 77429
Cell: 346-300-6202
Email: dmitchell73@pvamu

Dr. Mingli Han
Measurement Laboratory Instructor
Prairie View A&M University
S. R. Collins Engineering Technology Building
Room 311

November 11, 2021

Dear Dr. Han

The following pages are a detailed report of Lab 4 of MCEG 3011 Measurement Laboratory, "Gravity Measurement by Simple Pendulum". This report addresses the use of EES and pendulum for precise measurements as well as the use of statistical analysis of experimental data using the mean, deviation, the mean deviation, and the standard deviation. This lab was performed on October 19, 2021 and was submitted on November 2, 2021

If you have any questions or concerns, please call or email me at any time.

Sincerely,

Devan Mitchell
Enclosure: Lab Report

ABSTRACT

The purpose of this experiment was to introduce the use of EES to assist in the understanding of how to statistically analyze results derived from the pendulum. Using standard statistical analysis such as mean and deviation, the individual can analyze the results of the lab.

During the experiment, the methods that were used consisted of gathering data using a pendulum, also analyzing the data using statistical analysis formulas in EES.

From the lab, we can conclude that the data collected from the students from the pendulum are accurate.

In conclusion the individual should have gained knowledge in the use of the pendulum and EES. Also, further practice using statistical analysis.

The significance of the result is on gravitational acceleration value g and its uncertainty

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STATISTICAL ANALYSIS OF EXPERIMENTAL DATA – LOCAL GRAVITATIONAL ACCELERATION DETERMINATION BY A SIMPLE PENDULUM

Objective:

1. To determine the gravitational acceleration by a simple pendulum
(<https://www.youtube.com/watch?v=z6ZdhP167RY>)
2. To use EES for statistical analysis of experimental data and for computing the uncertainty in the computed variables
3. To present the computed physical quantity from measured data in the form of

$$g = g_m \pm \Delta g$$

Theory:

1. Error Computation

Errors or uncertainty involved in a result due to the uncertainties of the parameters involved in computations of measured values can be best obtained by using the Kline and McClintock formula also known as the Root-Sum-Square law. The formula is given as follows:

$$U_R = \left[\left(\frac{\partial R}{\partial X_1} U_{X_1} \right)^2 + \left(\frac{\partial R}{\partial X_2} U_{X_2} \right)^2 + \left(\frac{\partial R}{\partial X_3} U_{X_3} \right)^2 + \dots + \left(\frac{\partial R}{\partial X_N} U_{X_N} \right)^2 \right]^{\frac{1}{2}} \quad (1)$$

Where,

R	=	the result
U_R	=	uncertainty in the result
X_i	=	parameters involved in computing the result
U_{X_i}	=	uncertainty in the parameters X_i

Experiment

For a simple pendulum with small angular oscillation, neglecting friction, the frequency of oscillation f is given by

$$f = \frac{1}{2\pi} \sqrt{\frac{g}{L}} \quad (9)$$

Where

g	– local gravitational acceleration, m/s^2
L	– length of the string (pendulum length), m
f	– frequency of oscillation, cycles/s

if both side of equation (9) is squared, we get

$$f^2 = \frac{g}{4\pi^2} \frac{1}{L} \quad (10)$$

A graph of f^2 versus $1/L$ will be a straight line with a slope, S , given by

$$S = \frac{g}{4\pi^2} \quad (11)$$

from which g can be computed.

Statistical Analysis

The Mean: The mean x_m of a set of n data in which each data is represented by x_i ($i=1$ to n) is given by

$$x_m = \frac{1}{n} \sum_{i=1}^n x_i \quad (12)$$

The Deviation: The deviation d_i of a set of n data in which each data is represented by x_i ($i=1$ to n) is given by

$$d_i = |x_i - x_m| \quad (13)$$

Note that the average of the deviations of all the data is zero since the sum of the deviation is zero.

The Mean Deviation: The average of the absolute values of the deviations is however not zero, and is given by

$$\left| \bar{d}_i \right| = \frac{1}{n} \sum |x_i - x_m| \quad (14)$$

The Standard Deviation: The standard deviation is also known as the root mean square deviation. It is one of the most important statistical parameters that is used to ascertain the accuracy as well as the confidence one will have in the value of the measured data. The standard deviation for a very large set of data is given by

$$\sigma = \left[\frac{1}{n} \sum_{i=1}^n (x_i - x_m)^2 \right]^{1/2} \quad (15)$$

When the number of data is not large (greater than 20 for example), the sample standard deviation is given by

$$\sigma = \left[\frac{\sum (x_i - x_m)^2}{n-1} \right]^{1/2} \quad (16)$$

Apparatus:

String, weight, straight rule, stopwatch

Procedure:

Note: Each group perform the experiment at one nominal pendulum string length, L_{Nominal} . Each member in the group will then measure the actual pendulum length and then record one set of data.

1. Set the pendulum length to the approximate nominal length prescribed for the group
2. Measure the actual pendulum length in (cm).

3. Swing the pendulum at a small angle from the vertical and record the time required for 10 cycles of oscillations. Note that the count should start from zero (0) at the time the stopwatch is started.
4. Record the data on the raw data sheet.

Laboratory Report:

1. Set your Units to SI in EES
2. For each nominal length, input the actual lengths, L_1 , L_2 , L_3 , L_4 and L_5 in your EES program and use the average function to calculate the average length, L .
3. For each nominal length, input the times for 10 oscillations, T_1 , T_2 , T_3 , T_4 and T_5 in your EES program and use the average function to calculate the average time, T for 10 oscillations
4. Calculate the frequency, f , as $f=N/T$ where $N= 10$ oscillations.
5. Set $Y=f^2$ and $X=1/L$
6. For the data of the pendulum lengths measured, compute the sum of absolute deviations, d_L , the mean deviation, d_{mL} , and the standard deviation σ_L for the data at each nominal pendulum length.
7. For the data for the time, T , for 10 oscillations measured, compute the sum of absolute deviations, d_T , the mean deviation, d_{mT} , and the standard deviation σ_T for the data at each nominal pendulum length.
8. Run your program to ensure it works properly
9. Create a Table in EES with the columns L_1 , L_2 , L_3 , L_4 , L_5 , T_1 , T_2 , T_3 , T_4 , T_5 , L , T , f , X , Y , d_{mL} , σ_L , d_{mT} , and σ_T ,
10. Transfer the raw data into the EES table you have created.
11. Use the Solve table command to solve the table after commenting out the raw data variables in the program.
12. Plot Y versus X . This should come out as a straight line
13. Use EES to fit the best straight line through the points and note the statistics for the fit.
14. Plot the equation of the straight line on the plot and indicate the slope
15. Input the value of the slope, S , in your EES Equation and use Equation (3) to compute the value of g .
16. Using the maximum values of the standard deviations as the uncertainty in the experimental data, use EES to compute the uncertainty in the slope and in the computed value of g .

Formal Laboratory Report

1. Present the information in a well written standard laboratory report following the detailed report format provided to you and discussed in class.
2. Completely discuss and interpret your results including all graphs and computed results as required.

Table 1 **Sample** Experimental Data

Nominal Length	Length of Pendulum (cm)		Time for N=10 Oscillations (sec.)	
85cm	L1	85.1	T1	17.94
	L2	84.0	T2	19.10
	L3	85.0	T3	17.93
	L4	84.1	T4	17.89
	L5	85.0	T5	19.40
75cm	L1	75.5	T1	17.34
	L2	75.0	T2	17.35
	L3	74.9	T3	17.39
	L4	74.8	T4	17.45
	L5	75.1	T5	17.13
65cm	L1	65.4	T1	16.24
	L2	66.5	T2	16.25
	L3	65.1	T3	16.47
	L4	64.0	T4	16.23
	L5	65.3	T5	16.26
55cm	L1	55.0	T1	14.25
	L2	55.0	T2	15.24
	L3	55.0	T3	14.62
	L4	55.5	T4	15.19
	L5	55.0	T5	16.00
45cm	L1	45.2	T1	13.89
	L2	45.0	T2	13.83
	L3	45.0	T3	13.96
	L4	45.0	T4	13.60
	L5	45.2	T5	13.63
35cm	L1	36.5	T1	12.65
	L2	36.5	T2	12.71
	L3	36.5	T3	12.66
	L4	36.5	T4	11.97

should use the data we posted on canvas.



	L5	34.5	T5	11.60
--	----	------	----	-------

Solution

Uncertainty Results Solution

Unit Settings: SI C kPa kJ mass deg

Variables	Uncertainty	Partial derivative	% of uncertainty
$g = 9.57 \pm 15\%$			
$S = 0.2426 \pm 0.4019$		$\partial g / \partial S = 39.48$	100.00 %

No unit problems were detected.

Compilation time = 16 ms Calculation time = 14.39 s

2.1 Detailed Computer Analysis of All Data

Equations Window

Update Menu

☐ Hide vars used once

Main Program

$L_1=0$
 $L_2=0$
 $L_3=0$
 $L_4=0$
 $L_5=0$

$T_1=0$
 $T_2=0$
 $T_3=0$
 $T_4=0$
 $T_5=0$

$L = \text{average}(L_1, L_2, L_3, L_4, L_5) / 100$
 $t = \text{average}(T_1, T_2, T_3, T_4, T_5)$

$x = 1/L$
 $N = 10$
 $f = 1/t$
 $y = P/2$

$S = 0.2426$
 $g = 4^2 \pi^2 S$

US Line:22 Char:1 Wrap:On Insert Caps Lock:Off SI C kPa kJ mass deg Warnings:On Unit Chk:On Complex:Off Syntax Highlight:Off

2.2 Presentation of Tables of Derived Results

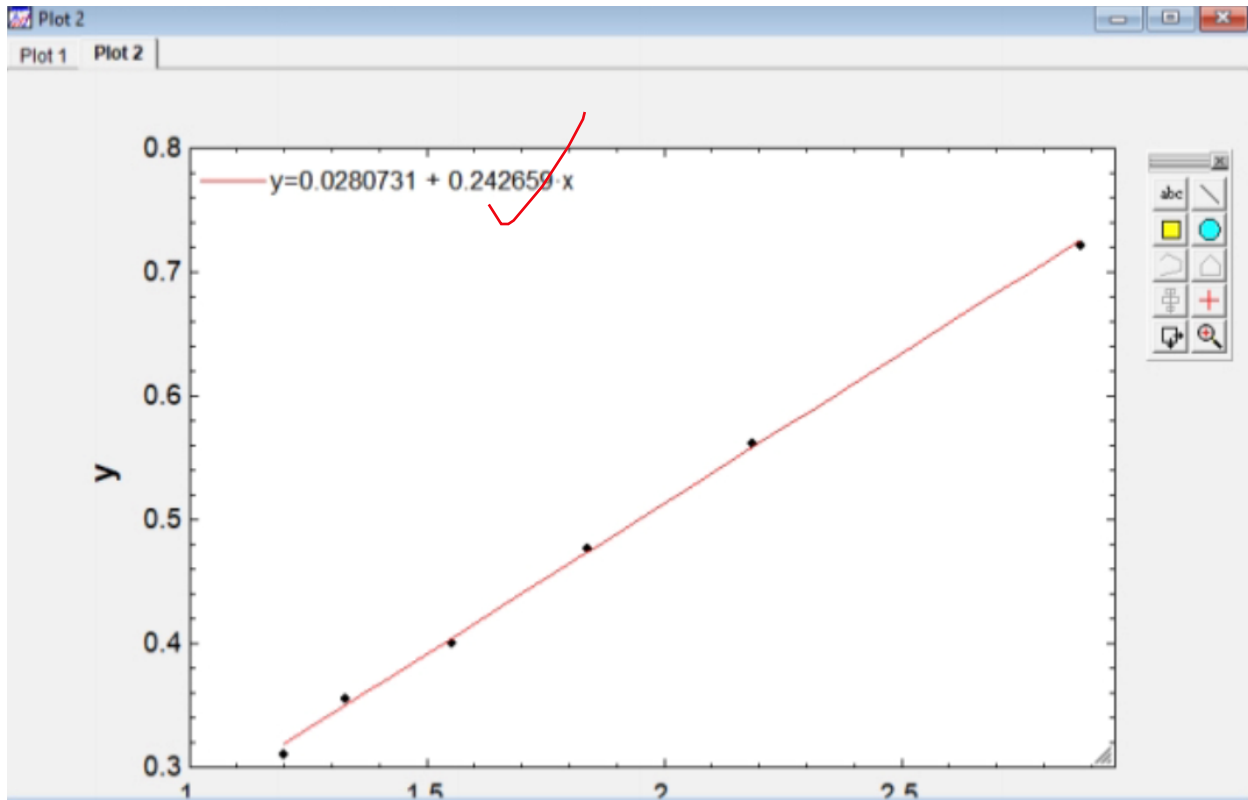
missing sigma of L and T

Parametric Table

Table 1

	L1	L2	L3	L4	L5	T1	T2	T3	T4	T5	L	t	x	y
Run 1	85.4	85.2	82	82.5	82	17.79	17.97	17.96	17.96	17.93				
Run 2	75.5	75.3	75.1	75.5	75.4	16.56	16.77	16.85	16.83	16.71	0.7536	16.74	1.327	0.3567
Run 3	64.5	64.6	63	65	64.8	15.9	15.74	15.68	15.8	15.76	0.6438	15.78	1.553	0.4018
Run 4	54.7	54.8	54.6	54	53.8	14.65	14.38	14.43	14.41	14.45	0.5438	14.46	1.839	0.478
Run 5	45.56	46	46	45.58	45.59	13.21	13.22	13.19	13.71	13.32	0.4575	13.33	2.186	0.5628
Run 6	34.7	34.8	34.9	34.7	34.6	11.77	11.76	11.74	11.78	11.76	0.3474	11.76	2.877	0.7228

3.1 Plotted Points



**MEASUREMENT AND INSTRUMENTATION LABORATORY
FALL 2021**

LABORATORY REPORT # 5

TOPICS COVERED IN LABORATORY EXPERIMENT #6

**EXPERIMENT #5
STRAIN MEASUREMENT USING STRAIN GAUGE
AND THE WHEATSTONE BRIDGE**

The objectives of the experiment are to:

- 1. To understand the theory of strain gauges and its application**
- 2. To show the equation used by the strain display**
- 3. To show and compare different strain bridge connections and show the linearity of the strain measurement**

**MEASUREMENT AND INSTRUMENTATION LABORATORY
FALL 2021**

LABORATORY HANDOUT FOR EXPERIMENT 5

**STRAIN MEASUREMENT USING STRAIN GAUGE
AND THE WHEATSTONE BRIDGE**

STRAIN MEASUREMENT USING STRAIN GAUGE AND THE WHEATSTONE BRIDGE

Objectives:

4. To understand the theory of strain gauges and its application
5. To show the equation used by the strain display
6. To show and compare different strain bridge connections and show the linearity of the strain measurement

Theory:

1. Strain Gauges

Strain Gauges are electrical sensors (transducers) that measure strains. Their electrical resistance changes by a small amount when an external force stretches or compresses them. This change in resistance is directly proportional to displacement (strain).

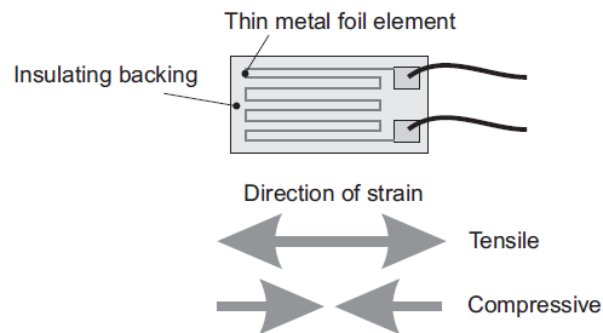


Figure 1 Simplified diagram of a strain gauge sensor

Strain gauges are small sheets of metal foil cut in a zigzag pattern. Figure 1 shows a simplified and enlarged version, Figure 2 shows a more realistic but enlarged drawing of a common strain gauge. They are only a few microns thick. Thus, for mechanical stability and electrical insulation, they are normally mounted on a backing sheet. The user bonds the gauges to the surface of the structural part under examination. The strain gauge stretches and compresses with the surface of the part that they are stuck to. Note that a negative strain reading is a compressive strain and a positive strain reading is a tensile strain.

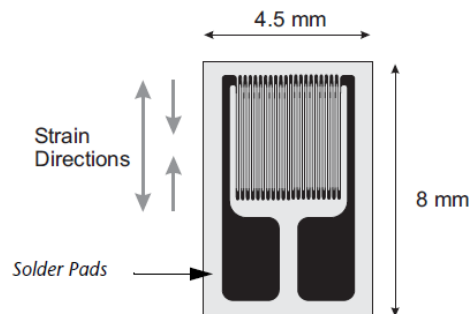


Figure 2 Enlarged and more realistic view of a common strain gauge

You must use a strain gauge in the right direction. It only works correctly when it measures strain in line with the elements of the gauge (see Figure 1). Strain gauges only give a very small resistance change (or no change at all) to strains that are not in line with the elements.

To give a direct reading of strain, instruments multiply the reading from a strain gauge by a constant called the **gauge factor**. The gauge factor is a measure of the strain gauges sensitivity to strain and varies slightly between different batches of the foil used to make the gauges. The gauge factor for standard metallic foil gauges usually varies between 1.9 and 2.3 for each batch.

Because strain gauges are made of thin strips of foil, their sensitivity to temperature (resistance change) is higher than a normal electrical wire conductor. Normally, their resistance increases as their temperature rises. Therefore, for reliable results where temperatures will change, engineers usually add temperature compensation to any circuit that includes the strain gauge.

2. Strain Gauge Rosettes

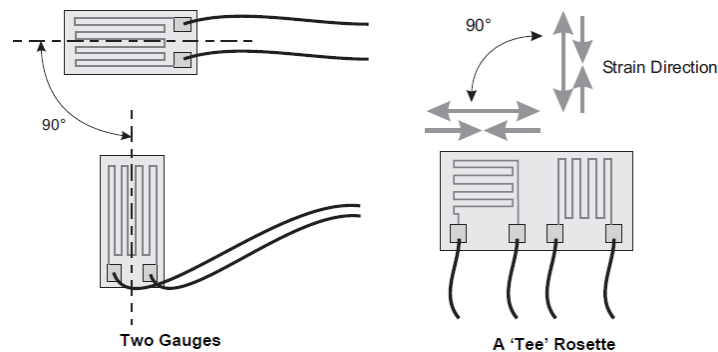


Figure 3 Two gauges at 90 degrees to each other and a 'T' rosette

When you need to measure strain in two or more different directions (at angles to each other), you can simply add extra strain gauges near to each other. However, strain gauges are usually very small and getting the angle right is difficult, so strain gauges can be bought as 'rosettes'. A rosette has two or more gauges already bonded to a backing material. Each gauge is accurately positioned by machines. This can save time and give more accurate and reliable readings. The Torsion System of the Strain Gauge Trainer has a bar that twists, so its stress and strain is actually at 45 degrees to the length of the bar. Special rosettes of two gauges at 45 degrees as shown in Figure 4 measure this strain.

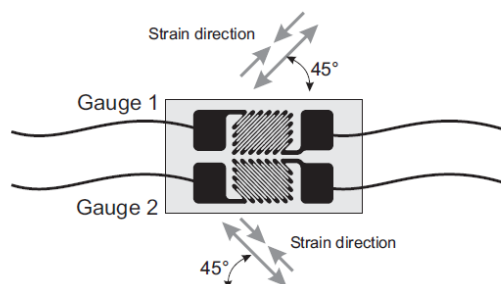


Figure 4 Shear and torque gauge rosette

3. The Wheatstone Bridge

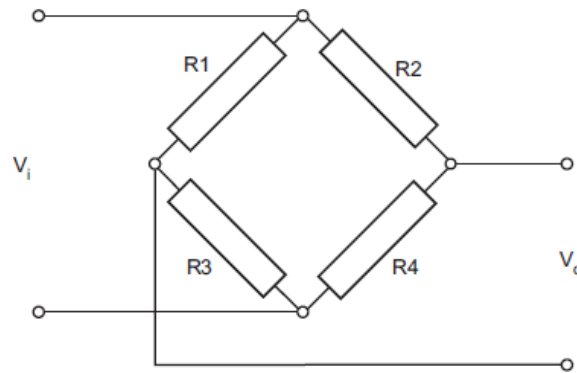


Figure 5 The Wheatstone Bridge

The basis of most strain measurement is the Wheatstone Bridge, shown in Figure 5. It has four identical resistance (R_1 , R_2 , R_3 and R_4) connected end to end in a diamond shape. An input voltage (V_i) connects two opposite connections. The output voltage is measured at the other two connections.

The output voltage (V_o) depends on the ratio of the resistors, so that:

$$V_o = V_i \frac{R_4}{R_2 + R_4} - V_i \frac{R_3}{R_1 + R_3} \text{ or } V_o = V_i \left(\frac{R_4}{R_2 + R_4} - \frac{R_3}{R_1 + R_3} \right)$$

As the equation shows, when R_1 , R_2 , R_3 and R_4 are all exactly equal, then the output voltage V_o is zero, no matter what happens to the input voltage V_i . However, if one resistance changes (for example, R_1), then V_o will change in proportion to the resistance change.

The Quarter Bridge Connection

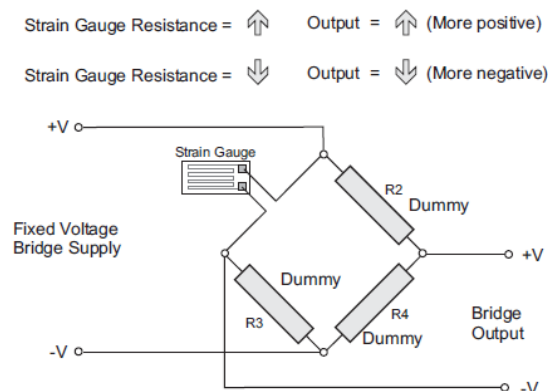


Figure 6 Quarter bridge connection – one active strain gauge

When a single strain gauge replaces one of the resistors, the output voltage V_o is proportional to the strain in the gauge. This is the **Quarter Bridge** connection (see Figure 6). When all resistors

are equal, the output potential difference is zero. As the strain gauge resistance increases (tensile strain), the output potential difference becomes more positive. As the strain gauge resistance decreases (compressive strain), the output potential difference becomes more negative.

Note that resistors R2, R3 and R4 are ‘dummy’ or ‘make-up’ resistors, matched to have exactly the same resistance as the unstressed strain gauge. This is a simple circuit and has no temperature compensation. The output from the bridge is not perfectly linear, but for normal resistance changes, the output is assumed to be linear.

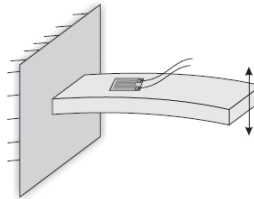


Figure 7 Application of a Quarter Bridge Strain Gauge

Half Bridge 1 (Opposite Arms)

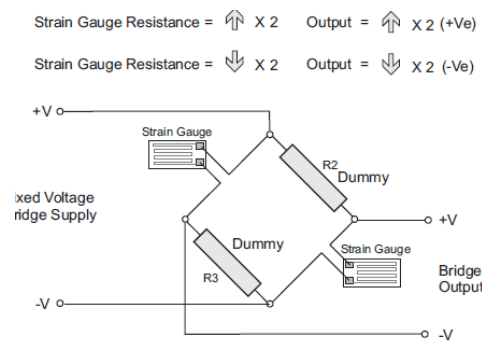


Figure 8 Half Bridge (opposite) connection

If the resistance of R1 and its opposite resistor (R4) both increase by the same amount, the output voltage changes twice as much as if only one resistor changes. This shows that you can get more output and therefore higher sensitivity if you use two identical strain gauges together. This connection is the **Half Bridge**, shown in Figure 8. Each gauge is opposite to the other, so both gauges must measure the same strain, so that they both change resistance in the same way (for example, both increases in resistance). Thus, two opposing gauges must measure the same type of strain (tensile or compressive) at the same place on the test structure. Note that this connection uses two dummy resistors, matched to have the same resistance as the gauges. The output from the bridge is not perfectly linear, but better than a quarter bridge. For normal strain gauge resistance changes, the output is assumed to be linear.

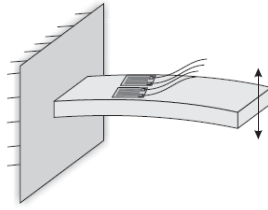


Figure 9 Application of an Opposite Half Bridge Strain Gauge

Half Bridge 2 (Adjacent Arms)

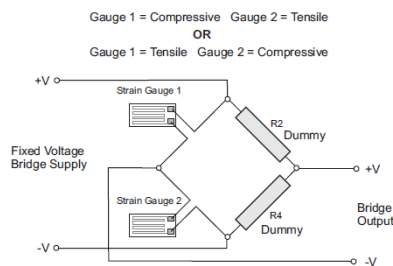


Figure 10 Half Bridge (adjacent) Connection

Figure 10 shows a half bridge connection with two adjacent strain gauges. In this case the changes in the strain gauge resistances will cancel out each other, so they must measure identical but opposite strains on the same part of the structure under test. One gauges must measure compressive strain and the other must measure tensile strain (or the opposite way around). When used in this way, this bridge will also give twice as much output as a quarter bridge. When both strains are equal in magnitude, the output from the bridge is almost linear.

Alternatively, one gauge can be fixed near to the other, but a place where there is no strain, but both gauges are always at the same temperature. This gauge will not measure strain, so the output is similar to the quarter bridge, but it will help to cancel any effects of temperature change. Again, the resistors are dummies, matched to the strain gauges.

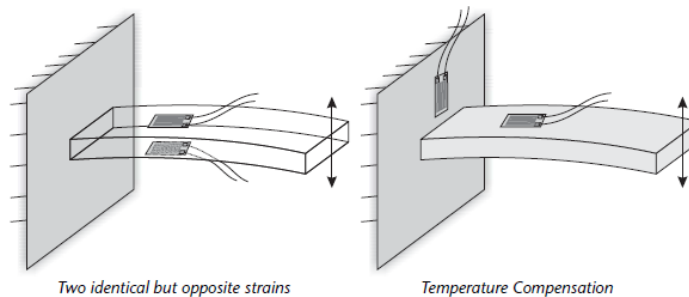


Figure 11 Application of the Adjacent Half Bridge Strain Gauge

Full Bridge

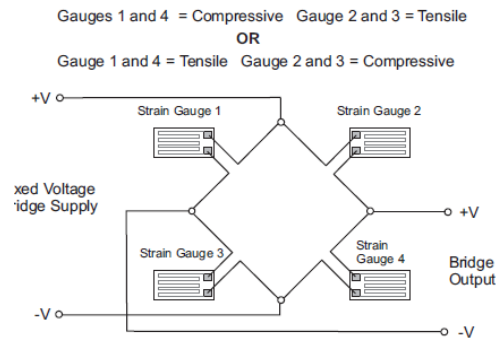


Figure 12 Full Bridge Connection

Figure 12 shows a **Full Bridge** connection, where four strain gauges form the bridge. This bridge gives twice as much voltage output and sensitivity than the standard half bridge (and four times the output of a quarter bridge). As in the half bridge, each opposite gauge must measure the same type of strain and the other two opposing gauges must measure the opposite type of strain on the same part of the structure. For example, gauges 1 and 4 must measure tensile strain, while gauges 2 and 3 must measure compressive strain, or the other way around. When all strains are equal in magnitude, the output from the bridge is linear.

Alternatively, two adjacent gauges (for example 2 and 4) can be fixed near to the other gauges, but at a place where there is no strain, but all gauges are always at the same temperature. These gauges will not measure any strain, so the output will be similar to the half bridge, but they will help to cancel out any effects of temperature change.

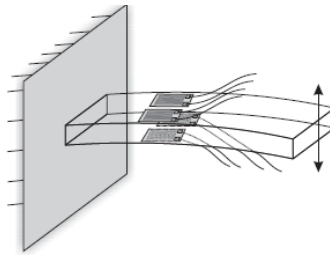


Figure 13 Application of Full Bridge Strain Gauge

4. Strain Bridge Equation

To calculate the strain from the dc voltage across the bridge, the Strain Display uses a standard equation:

$$\epsilon = 4 \times \frac{V_o}{GF \times V_i \times N} \quad (1)$$

Where

ϵ = Strain

V_o = Voltage measured across the bridge (V)

GF = Gauge Factor

V_i = Fixed Input Voltage applied to the bridge (V)

N = Number of active arms (gauges connected)

The output is then multiplied by 10^6 to give a result in $\mu\epsilon$ (micro strain)

Apparatus:

The equipment for this experiment is the strain gauge trainer shown in Figure 14.

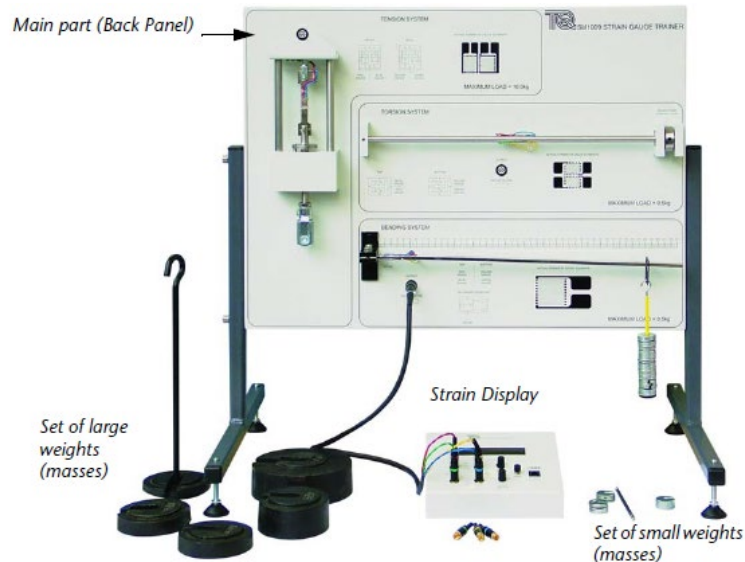


Figure 14 The strain gauge trainer

It contains the tension system, the torsion system and the bending system. The Bending System is a solid, rectangular section cantilever beam. This is a specimen beam held securely at one end. It simulates many different mechanical and constructional things such as: aeroplane wings, swimming pool diving boards, bridges, balcony supports on buildings, and shelf supports. A secure clamp holds the specimen beam at one end. A cantilever can bend or 'deflect' upwards or downwards, this experiment bends the beam downwards. Four standard strain gauges measure the tensile and compressive strains directly in line with the beam. Two gauges measure the tensile strain on the top of the beam. The other two gauges measure the compressive strain underneath the beam.

The strain display shown in Figure 15 is a metal box with a display, controls and input sockets. The input sockets accept the signals from the color-coded gauges on the three different systems of the Strain Gauge Trainer. The multiline display shows the output voltage measured across the strain bridge and automatically calculates and displays the strain. You set the Strain Display to match your chosen strain gauge connections and their gauge factor. Supplied with the equipment are special plugs with built-in high precision dummy resistors, for use when you only measure one or two active arms (gauges). The gauge factor control allows the user to set the gauge factor of the strain gauge that they connect to. A zero button allows the user to zero (or null) the readings before each experiment. The display uses the voltage output from the gauges to calculate the strain. A configuration switch changes the calculations of the Strain Display, so that it shows the correct strain for any bridge connection.

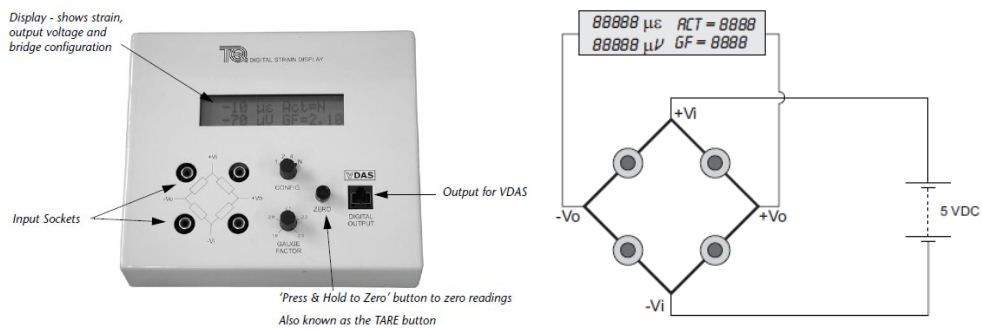


Figure 14 The strain gauge trainer and its basic circuit

Note from the basic circuit of the Strain Display, the fixed bridge voltage V_i is 5 volts.

Procedure:

1. Create four blank results tables, each similar to Table 1.
2. Connect the strain connection cable to the output socket of the Bending System.

Table 1 Results Table of Quarter Bridge Connection.

Bridge Connection: Quarter Bridge Load Position: 420 mm		Active Arms: 1 Gauge Factor: 2.16	
Load (g)	Strain Reading ($\mu\epsilon$)	Output (μV)	Calculated Strain ($\mu\epsilon$)
0			
50			
100			
150			
200			
250			
300			
350			
400			
450			
500			

Quarter Bridge Connection

3. Connect only the red gauge (red wire and plug) to the strain display as a quarter bridge connection. Fit dummy plugs to the other three sockets.
4. Switch on the power to the strain display. Adjust the configuration control to 1 (1 active arm). Adjust the gauge factor to be the same as written on the back plate near the bending system.
5. In your results table, note the gauge factor and active arms setting.
6. Carefully slide a knife-edge hanger onto the beam to the 420 mm position. Leave the equipment to stabilize for approximately one minute, then press and hold the 'zero' button until the display reading become 0 (zero).
7. Note the output voltage and strain readings in your table.
8. Hook a small weight hanger to the knife-edge hanger.
9. The small weight hanger is 10 g. Add 4 x 10 g weights to the weight hanger to give a total weight (load) of 50 g. Note the output voltage and strain readings into your table.
10. In increments of 50 g, add more weights to the weight hanger until you reach 500 g. At each increment, note the output voltage and strain readings into your table.



Do not add more than 500 g load to the beam.

Only use the small weights for this experiment.

Half Bridge 1 Connection – Opposite Arms (two gauges measure the same strain)

11. Repeat the experiment but:
 - Connect the red gauge and the blue gauge to the strain display as a half bridge (opposite arms) connection.
 - Fit dummy plugs to the other two sockets.
 - Adjust the configuration control to Act = 2 (2 active arms).

Half Bridge 2 Connection – Adjacent Arms (two gauges measure the opposite strain)

12. Repeat the experiment but:
 - Connect the red gauge and the green gauge to the strain display as a half bridge (adjacent arms) connection.
 - Fit dummy plugs to the other two sockets.
 - Adjust the configuration control to Act = 2 (2 active arms).

Full Bridge Connection

13. Repeat the experiment but:
 - Connect the red gauge and the blue gauge to opposite sockets.
 - Connect the yellow gauge and the green gauge to opposite sockets, to complete a full bridge connection.

- Adjust the configuration control to Act = 4 (4 active arms).

Results Analysis

1. To complete each set of results, use Equation (1) and the bridge output voltage to calculate the strain. Is the calculated value of strain the same as that displayed by the Strain Display?
2. Using EES, create parametric tables (4 tables) and variables for each bridge configuration
3. For each bridge configuration, plot **strain reading** versus the output voltage, use the **strain reading** (not calculated strain) as the horizontal axis and the output voltage as the vertical axis (4 plots). Fit the best straight line through the data points. Are all the results linear?
4. Compare the output voltage and strain reading for each bridge configuration. You should note that strain values are similar for each load, how about the output voltages? The ratio of voltage and strain tells the sensitivity of the strain bridge. Based on the collected data and plots, please compare and discuss the sensitivity of the four different strain bridge.
5. Complete your report using the standard format for lab reporting.

ABOVE AVERAGE

**MECHANICAL ENGINEERING DEPARTMENT
PRAIRIE VIEW A&M UNIVERSITY**



MCEG 3101 MEASUREMENT LABORATORY

Fall 2021 Section P01

LABORATORY REPORT ON

“Strain Measurement Using Strain Gauge and Wheatstone Bridge”

**Conducted on
November 9, 2021**

**Submitted by
Anette Lira
On
December 10, 2021**

**To
Dr. Mingli Han
*Measurement Laboratory Instructor***

MECHANICAL ENGINEERING DEPARTMENT

**MEASUREMENT LABORATORY GRADING SHEET
FALL 2021 SECTION P01**

Title of Experiment: Local Gravitational Acceleration Determination by a Simple Pendulum.

Name: Anette Lira

Date Lab was Performed: 11/09/2021 Report Due Date: 12/10/2021

<i>Ability to Conduct Experiments</i>	MAX	Your Score	Comments
Ability to demonstrate general lab safety (by your conduct and observations).	3	3	
Ability to follow the procedure and properly rephrasing the procedure to reflect what you did during the experiment.	7	7	
Ability to demonstrate knowledge of how equipment function, their limitations, and the uncertainty associated with reading the instruments.	5	5	
Ability to collect and record the raw data using appropriate units of measurement and identify the dependent and independent variables in the experiment.	5	5	
Total for Ability to Conduct Experiments	20		
Percentage for this Performance Criteria			
<i>Ability to Analyze and Interpret experimental Data in a Formal Report</i>			
Report format (Ability to properly format and present a technical report)	13	11	
Provides appropriate abstracts for the experimental report	5	4	
Ability to analyze the data using appropriate software to generate the required parameters using consistent units	27	27	
Ability to present the data (raw /derived) in tabular and graphical form to meet the objectives and to aid in interpretation.	14	14	
Ability to discuss the raw and derived data/graphs and assess the validity of the results in relation to the underlying theory and expected trends.	14	12	
Ability to draw appropriate and reasonable conclusions in relations to each of the experimental objectives. One conclusion statement for each objective.	7	7	
Total for Ability to Analyze and Interpret experimental Data	80		
TOTAL FOR THIS LAB		95	

Anette Lira
Mechanical Engineering Student
2763 Picasso Lane
Brownsville Tx 78520
Cell: 956-295-0756
E-mail: alira@pvamu.edu

Dr. Mingli Han
Measurement Laboratory Instructor
Prairie View A&M University
S. R. Collins Engineering Technology Building Room 311

Dear Dr. Han:

October 19, 2021

The following pages are a detailed report for lab 5 of MCEG 3101 Measurement Laboratory, "Strain Measurement Using Strain Gauge and Wheatstone Bridge ". This report addresses the measurement of strain and by using the strain gauges and Wheatstone. We will also use the engineering equation solver to obtain statistical analysis of the experimental data. The lab was performed on November 09, 2021 and was submitted on December 10 , 2021.

If you have any questions or concerns, please call, or email me at any time.

Sincerely,

Anette Lira
Enclosure: Lab Report

Abstract

The purpose of this experiment is to understand how strain gauges show the strain with different load applied to the apparatus. The strain gauge also shows and compared the equations performed in the lab. Each group got their own data and combined we obtain the experimental data that was given by Dr. Han. By completing the experiment, we determine the results and compare different strain bridge connections and show the linearity of strain measurement, therefore it shows the importance of measurement. The procedure used in this lab to analyze the different strain measurements was to use a Quarter bridge that we connected only to the red gauge arm, the slide knife edge hanger onto the beam to the 420mm position. After this we added the weight by increasing 50g on the weight hanger until we reached to 500g. Then we collected all the data and repeated the same experiment with half bridge, then 1 and 2 connections and the full bridge. Using EES we were able to calculate the data for each bridge and using a graph to compare the strain read vs the output with the data collected in the lab performed.

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STRAIN MEASUREMENT USING STRAIN GAUGE AND THE WHEATSTONE BRIDGE

1.1 OBJECTIVES OF THE EXPERIMENT

- 2 To understand the theory of strain gauges and its application
- 3 To show the equation used by the strain display
- 4 To show and compare different strain bridge connections and show the linearity of strain measurement

1.2 THEORY

1 Strain Gauges

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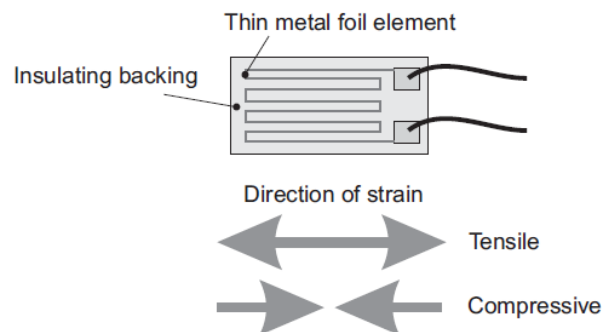


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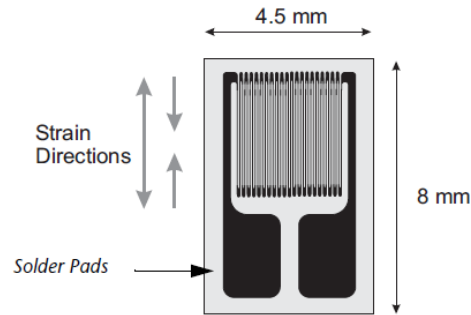


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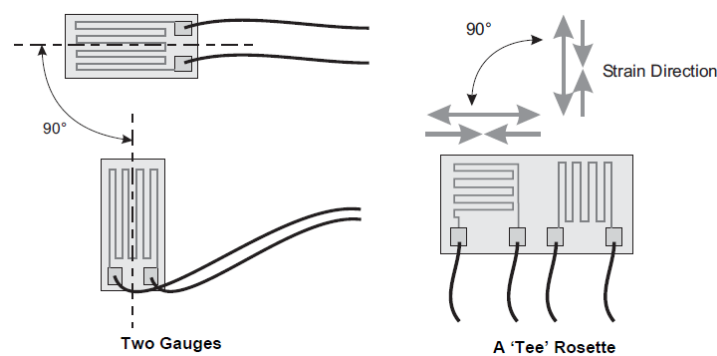


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When you need to measure strain in two or more different directions (at angles to each other), you can simply add extra strain gauges near to each other. However, strain gauges are usually very small and getting the angle right is difficult, so strain gauges can be bought as 'rosettes'. A rosette has two or more gauges already bonded to a backing material. Each gauge is accurately positioned by machines. This can save time and give more

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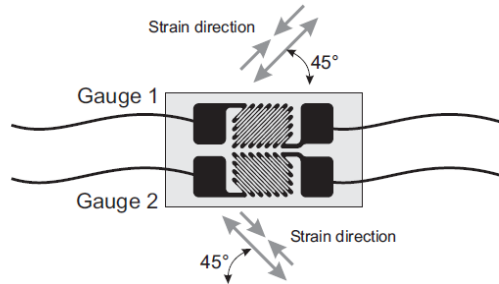


Figure 1.5 Shear and torque gauge rosette

3 The Wheatstone Bridge

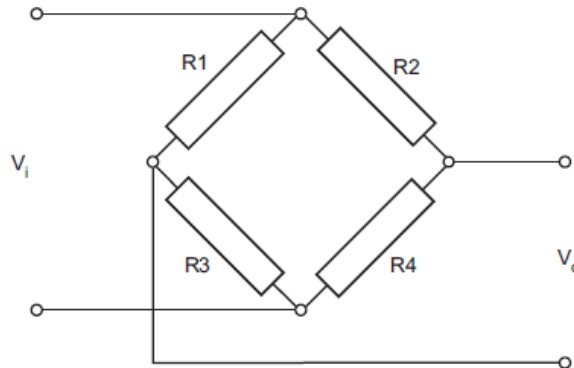


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As the equation shows, when R_1 , R_2 , R_3 and R_4 are all exactly equal, then the output voltage V_o is zero, no matter what happens to the input voltage V_i . However, if one resistance changes (for example, R_1), then V_o will change in proportion to the resistance change

The Quarter Bridge Connection

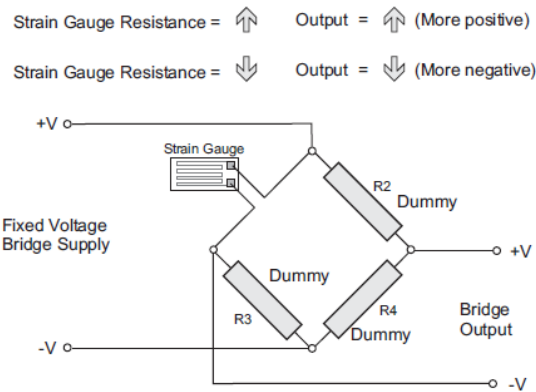


Figure 1.6 Quarter bridge connection – one active strain gauge

When a single strain gauge replaces one of the resistors, the output voltage V_o is proportional to the strain in the gauge. This is the **Quarter Bridge** connection (see Figure 6). When all resistors are equal, the output potential difference is zero. As the strain gauge resistance increases (tensile strain), the output potential difference becomes more positive. As the strain gauge resistance decreases (compressive strain), the output potential difference becomes more negative.

Note that resistors R2, R3 and R4 are ‘dummy’ or ‘make-up’ resistors, matched to have exactly the same resistance as the unstressed strain gauge. This is a simple circuit and has no temperature compensation. The output from the bridge is not perfectly linear, but for normal resistance changes, the output is assumed to be linear.

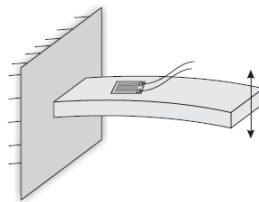


Figure 1.7 Application of a Quarter Bridge Strain Gauge

Half Bridge 1 (Opposite Arms)

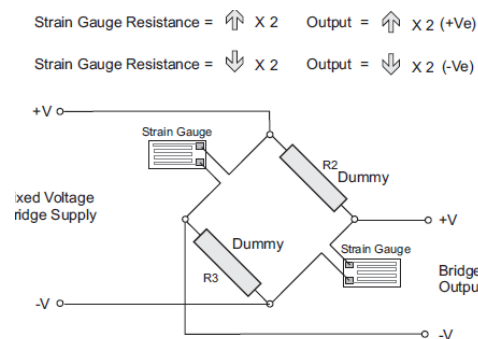


Figure 1.8 Half Bridge (opposite) connection

If the

resistance of R1

and its opposite resistor (R_4) both increase by the same amount, the output voltage changes twice as much as if only one resistor changes. This shows that you can get more output and therefore higher sensitivity if you use two identical strain gauges together. This connection is the **Half Bridge**, shown in Figure 8. Each gauge is opposite to the other, so both gauges must measure the same strain, so that they both change resistance in the same way (for example, both increases in resistance). Thus, two opposing gauges must measure the same type of strain (tensile or compressive) at the same place on the test structure. Note that this connection uses two dummy resistors, matched to have the same resistance as the gauges. The output from the bridge is not perfectly linear, but better than a quarter bridge. For normal strain gauge resistance changes, the output is assumed to be linear.

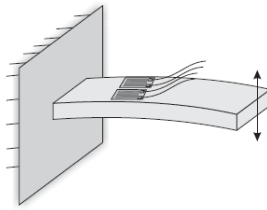


Figure 1.9 Application of an Opposite Half Bridge Strain Gauge

Half Bridge 2 (Adjacent Arms)

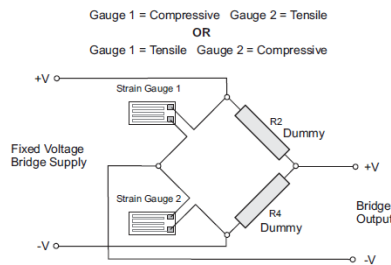


Figure 1.10 Half Bridge (adjacent) Connection

Figure 10 shows a half bridge connection with two adjacent strain gauges. In this case the changes in the strain gauge resistances will cancel out each other, so they must measure identical but opposite strains on the same part of the structure under test. One gauges must measure compressive strain and the other must measure tensile strain (or the opposite way around). When used in this way, this bridge will also give twice as much output as a quarter bridge. When both strains are equal in magnitude, the output from the bridge is almost linear.

Alternatively, one gauge can be fixed near to the other, but a place where there is no strain, but both gauges are always at the same temperature. This gauge will not measure strain, so the output is similar to the quarter bridge, but it will help to cancel any effects of temperature change. Again, the resistors are dummies, matched to the strain gauges.

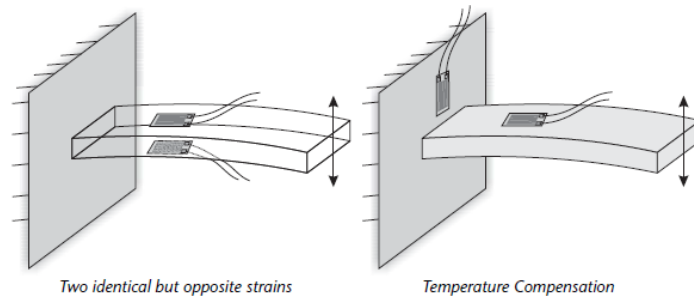


Figure 1.11 Application of the Adjacent Half Bridge Strain Gauge

Full Bridge

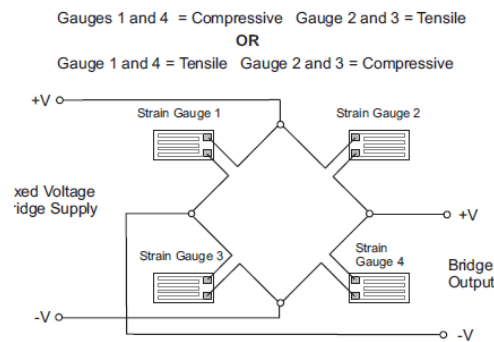


Figure 1.12 Full Bridge Connection

Figure 12 shows a **Full Bridge** connection, where four strain gauges form the bridge. This bridge gives twice as much voltage output and sensitivity than the standard half bridge (and four times the output of a quarter bridge). As in the half bridge, each opposite gauge must measure the same type of strain and the other two opposing gauges must measure the opposite type of strain on the same part of the structure. For example, gauges 1 and 4 must measure tensile strain, while gauges 2 and 3 must measure compressive strain, or the other way around. When all strains are equal in magnitude, the output from the bridge is linear.

Alternatively, two adjacent gauges (for example 2 and 4) can be fixed near to the other gauges, but at a place where there is no strain, but all gauges are always at the same temperature. These gauges will not measure any strain, so the output will be similar to the half bridge, but they will help to cancel out any effects of temperature change.

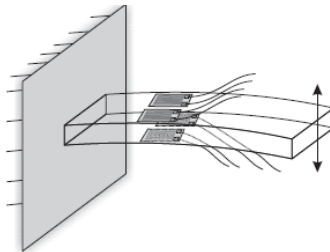


Figure 1.13 Application of Full Bridge Strain Gauge

4 Strain Bridge Equation

To calculate the strain from the dc voltage across the bridge, the Strain Display uses a standard equation:

$$\epsilon = 4 \times \frac{V_o}{GF \times V_i \times N} \quad (1)$$

Where

ϵ = Strain

V_o = Voltage measured across the bridge (V)

GF = Gauge Factor

V_i = Fixed Input Voltage applied to the bridge (V)

N = Number of active arms (gauges connected)

The output is then multiplied by 10^6 to give a result in $\mu\epsilon$ (micro strain)

1.3 Apparatus

The equipment for this experiment is the strain gauge trainer shown in Figure 6: 1.3.6.

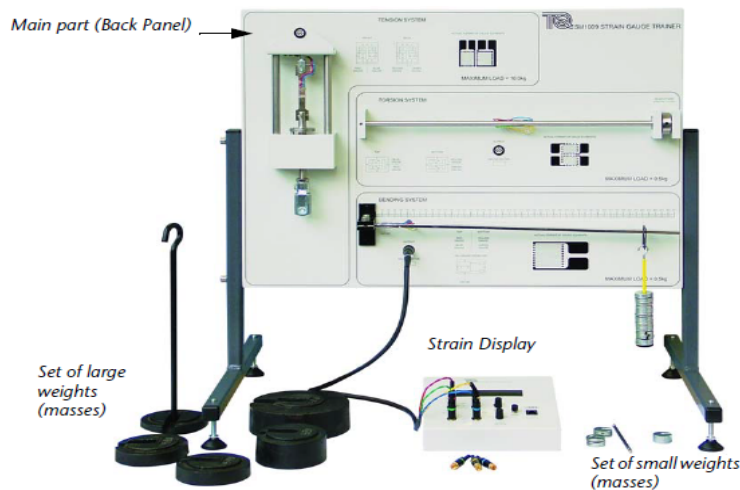


Figure 1.14 The equipment

It contains the tension system, the torsion system and the bending system. The Bending System is a solid, rectangular section cantilever beam. This is a specimen beam held securely at one end. It simulates many different mechanical and constructional things such as: aero plane wings, swimming pool diving boards, bridges, balcony supports on buildings, and shelf supports. A secure clamp holds the specimen beam at one end. A cantilever can bend or 'deflect' upwards or downwards, this experiment bends the beam downwards. Four standard strain gauges measure the tensile and compressive strains directly in line with the beam. Two gauges measure the tensile strain on the top of the beam.

The strain display shown in Figure 7: 1.3.7 is a metal box with a display, controls and input sockets. The input sockets accept the signals from the color-coded gauges on the three different systems of the Strain Gauge Trainer. The multiline display shows the output voltage measured across the strain bridge and automatically calculates and displays the strain. You set the Strain Display to match your chosen strain gauge connections and their gauge factor. Supplied with the equipment are special plugs with built-in high precision dummy resistors, for use when you only measure one or two active arms (gauges). The gauge factor control allows the user to set the gauge factor of the strain gauge that they connect to. A zero button allows the user to zero (or null) the readings before each experiment. The display uses the voltage output from the gauges to calculate the strain. A configuration switch changes the calculations of the Strain Display, so that it shows the correct strain for any bridge connection.

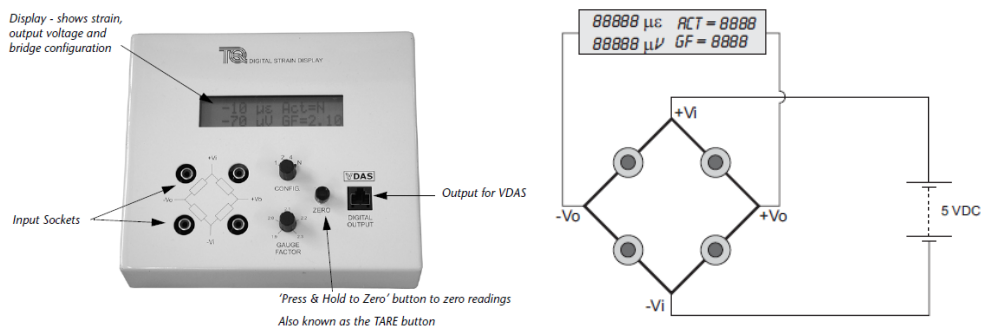


Figure 1.15 Metal box with display

Note from the basic circuit of the Strain Display, the fixed bridge voltage V_i is 5 volts.

1.4 Experimental Safety:

1. Read and follow lab instructions carefully.
2. Lab equipment may only be used by students under instructors' supervision.
3. No eating, smoking or drinking in the lab.
4. Proper clothing must always be worn in the laboratory.

1.5 Procedure

1. Create four blank results tables, each similar to Table 1.
2. Connect the strain connection cable to the output socket of the Bending System.

Table 1.1 Results Table of Quarter Bridge Connection.

Bridge Connection: Quarter Bridge Load Position: 420 mm		Active Arms: 1 Gauge Factor: 2.16	
Load (g)	Strain Reading ($\mu\epsilon$)	Output (μV)	Calculated Strain ($\mu\epsilon$)
0			
50			
100			
150			
200			
250			
300			
350			
400			
450			
500			

Quarter Bridge Connection

3. Connect only the red gauge (red wire and plug) to the strain display as a quarter bridge connection. Fit dummy plugs to the other three sockets.
4. Switch on the power to the strain display. Adjust the configuration control to 1 (1 active arm). Adjust the gauge factor to be the same as written on the back plate near the bending system.
5. In your results table, note the gauge factor and active arms setting.
6. Carefully slide a knife-edge hanger onto the beam to the 420 mm position. Leave the equipment to stabilize for approximately one minute, then press and hold the 'zero' button until the display reading become 0 (zero).
7. Note the output voltage and strain readings in your table.
8. Hook a small weight hanger to the knife-edge hanger.
9. The small weight hanger is 10 g. Add 4 x 10 g weights to the weight hanger to give a total weight (load) of 50 g. Note the output voltage and strain readings into your table.

10. In increments of 50 g, add more weights to the weight hanger until you reach 500 g. At each increment, note the output voltage and strain readings into your table.



*Do not add more than 500 g load to the beam.
Only use the small weights for this experiment.*

Half Bridge 1 Connection – Opposite Arms (two gauges measure the same strain)

11. Repeat the experiment but:
- Connect the red gauge and the blue gauge to the strain display as a half bridge (opposite arms) connection.
 - Fit dummy plugs to the other two sockets.
 - Adjust the configuration control to Act = 2 (2 active arms).

Half Bridge 2 Connection – Adjacent Arms (two gauges measure the opposite strain)

12. Repeat the experiment but:
- Connect the red gauge and the green gauge to the strain display as a half bridge (adjacent arms) connection.
 - Fit dummy plugs to the other two sockets.
 - Adjust the configuration control to Act = 2 (2 active arms).

Full Bridge Connection

13. Repeat the experiment but:
- Connect the red gauge and the blue gauge to opposite sockets.
 - Connect the yellow gauge and the green gauge to opposite sockets, to complete a full bridge connection.
 - Adjust the configuration control to Act = 4 (4 active arms).

1.6 Presentation of Raw Experimental data

Table 1.2 Quarter Bridge

Quarter Bridge		Active arm: 1	
Load position: 420mm		Gauge factor: 2.16	
Load (g)	Strain Reading ($\mu\epsilon$)	Output (μV)	Calculated strain ($\mu\epsilon$)
0	0	0	
50	13	36	
100	27	74	
150	40	110	
200	55	150	
250	69	188	
300	83	225	
350	97	263	
400	109	296	
450	123	334	
500	137	371	

Table 1.3 Half Bridge 1

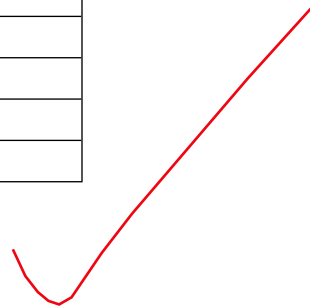
Half Bridge 1 (Opposite Arm)		Active arm: 2	
Load position: 420mm		Gauge factor: 2.16	
Load (g)	Strain Reading ($\mu\epsilon$)	Output (μV)	Calculated strain ($\mu\epsilon$)
0	0	0	
50	16	90	
100	30	162	
150	43	235	
200	56	306	
250	69	374	
300	82	447	
350	95	519	
400	109	592	
450	122	664	
500	136	737	

Table 1.4 Half bridge 2

Half Bridge 2 (Adjacent Arm)		Active arm: 2	
Load position: 420mm		Gauge factor: 2.16	
Load (g)	Strain Reading ($\mu\epsilon$)	Output (μV)	Calculated strain ($\mu\epsilon$)
0	0	0	
50	16	89	
100	31	169	
150	45	245	
200	59	320	
250	72	392	
300	86	465	
350	100	542	
400	113	613	
450	127	690	
500	140	755	

Table 1.5 Full Bridge

Full Bridge		Active arm: 4	
Load position: 420mm		Gauge factor: 2.16	
Load (g)	Strain Reading ($\mu\epsilon$)	Output (μV)	Calculated strain ($\mu\epsilon$)
0	0	0	
50	17	190	
100	34	367	
150	45	485	
200	59	778	
250	72	778	
300	85	925	
350	99	1072	
400	112	1357	
450	125	1357	
500	138	1500	



CHAPTER 2

ABILITY TO ANALYZE EXPERIMENTAL DATA

2.1 Detailed computer analysis of all data

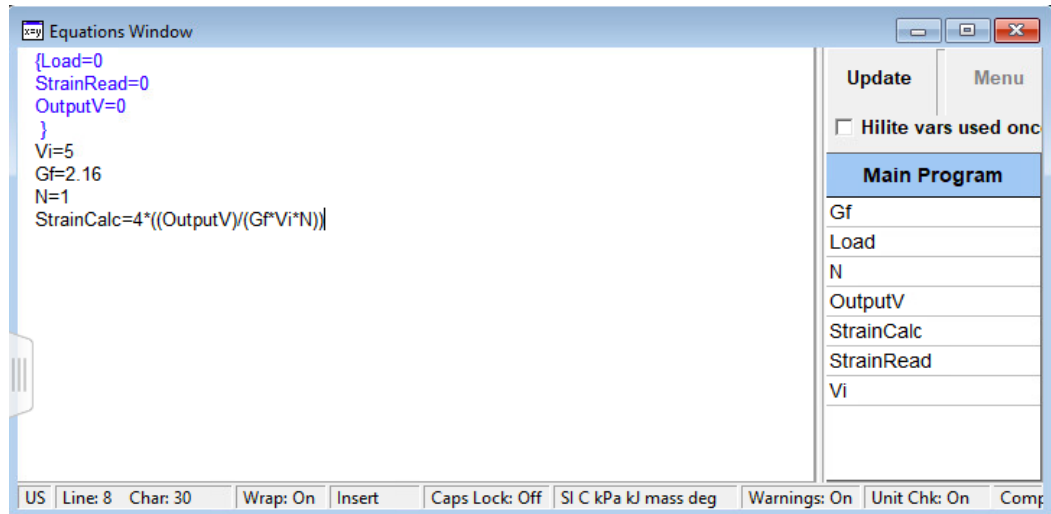


Figure 2.1 Quarter Bridge code

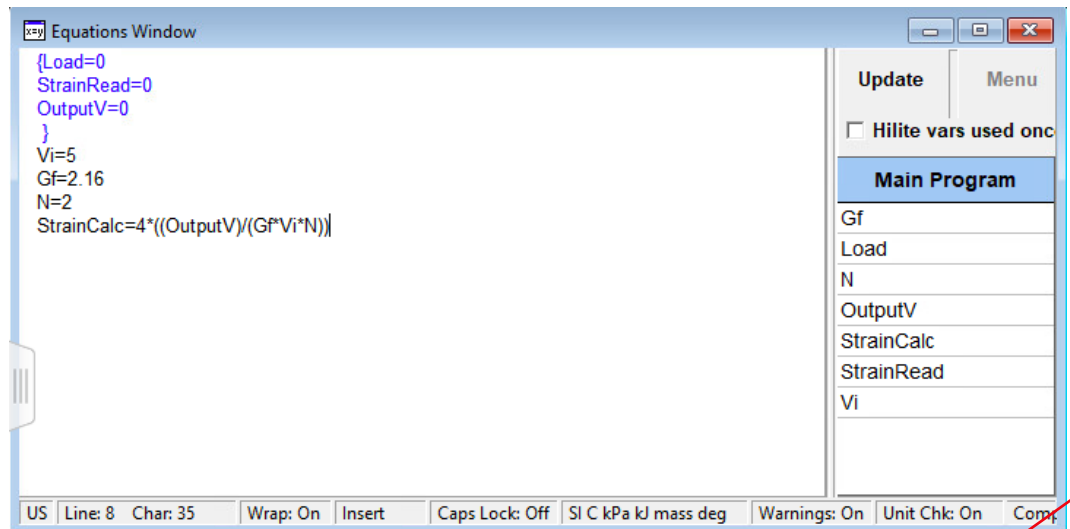


Figure 2.2 Half Bridge 1

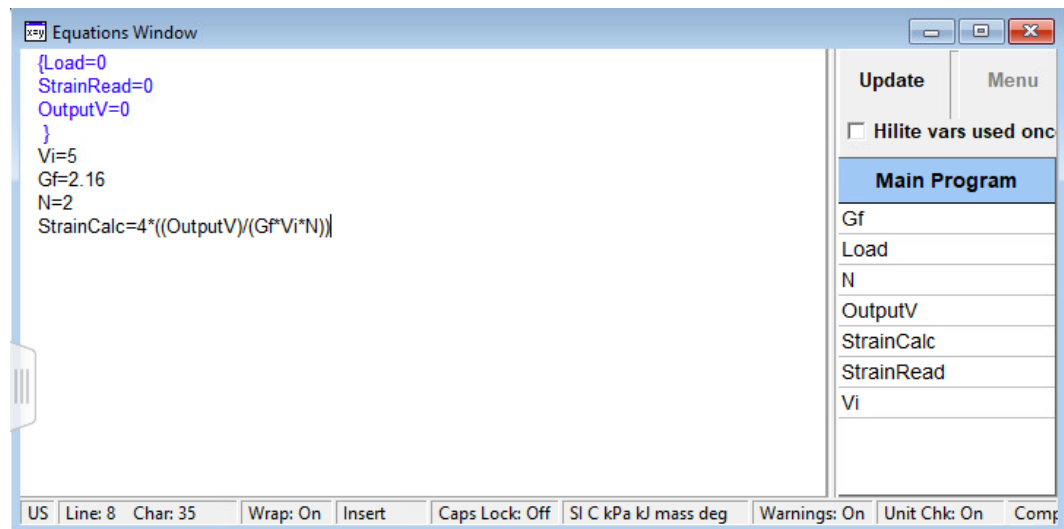


Figure 2.3 Half Bridge 2

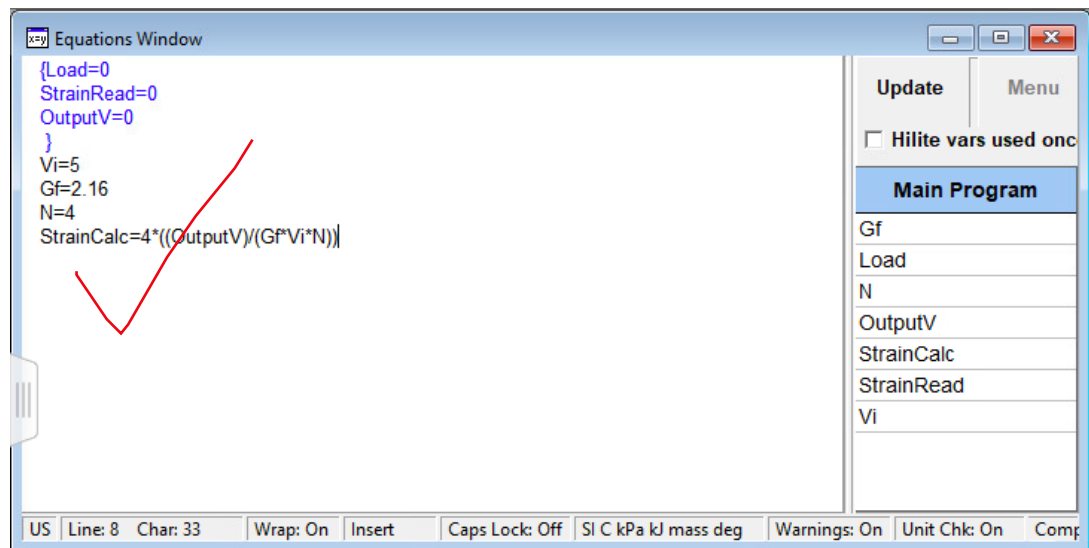


Figure 2.4 Full Bridge

2.2 Presentation of Tables of derived results

Table 2.1 Parametric table for Quarter Bridge

Table 1	1	2	3	4
1..11	Load	StrainRead	OutputV	StrainCalc
Run 1	0	0	0	0
Run 2	50	13	36	13.33
Run 3	100	27	74	27.41
Run 4	150	40	110	40.74
Run 5	200	55	150	55.56
Run 6	250	69	188	69.63
Run 7	300	83	225	83.33
Run 8	350	97	263	97.41
Run 9	400	109	296	109.6
Run 10	450	123	334	123.7
Run 11	500	137	371	137.4

Discussion: In this table we have the derived results of the EES program with the coding equations in the figure 2.1 for the quarter bridge.

Table 2.2 Parametric table for Half Bridge 1

Table 1	1	2	3	4
1..11	Load	StrainRead	OutputV	StrainCalc
Run 1	0	0	0	0
Run 2	50	16	90	16.67
Run 3	100	30	162	30
Run 4	150	43	235	43.52
Run 5	200	56	306	56.67
Run 6	250	69	374	69.26
Run 7	300	82	447	82.78
Run 8	350	95	519	96.11
Run 9	400	109	592	109.6
Run 10	450	122	664	123
Run 11	500	136	737	136.5

Discussion: In this table we have the derived results of the EES program with the coding equations in the figure 2.2 for the half bridge 1.

Table 2.3 Parametric Table for Half Bridge 2

Table 1	1	2	3	4
1..11	Load	StrainRead	OutputV	StainCalc
Run 1	0	0	0	0
Run 2	50	16	89	16.48
Run 3	100	31	169	31.3
Run 4	150	45	245	45.37
Run 5	200	59	320	59.26
Run 6	250	72	392	72.59
Run 7	300	86	465	86.11
Run 8	350	100	542	100.4
Run 9	400	113	613	113.5
Run 10	450	127	690	127.8
Run 11	500	140	755	139.8

Discussion: In this table we have the derived results of the EES program with the coding equations in the figure 2.3 for the half bridge 2.

Table 2.4 Parametric Table for full bridge

Table 1	1	2	3	4
1..11	Load	StrainRead	OutputV	StrainCalc
Run 1	0	0	0	0
Run 2	50	17	190	17.59
Run 3	100	34	367	33.98
Run 4	150	45	485	44.91
Run 5	200	59	778	72.04
Run 6	250	72	778	72.04
Run 7	300	85	925	85.65
Run 8	350	99	1072	99.26
Run 9	400	112	1357	125.6
Run 10	450	125	1357	125.6
Run 11	500	138	1500	138.9

Discussion: In this table we have the derived results of the EES program with the coding equations in the figure 2.4 for the full bridge.

CHAPTER 3

ABILITY TO INTERPRET EXPERIMENTAL DATA

3.1 Presentation of Graphs/Figures and Interpretation of Results Presented by each Graph/Figure

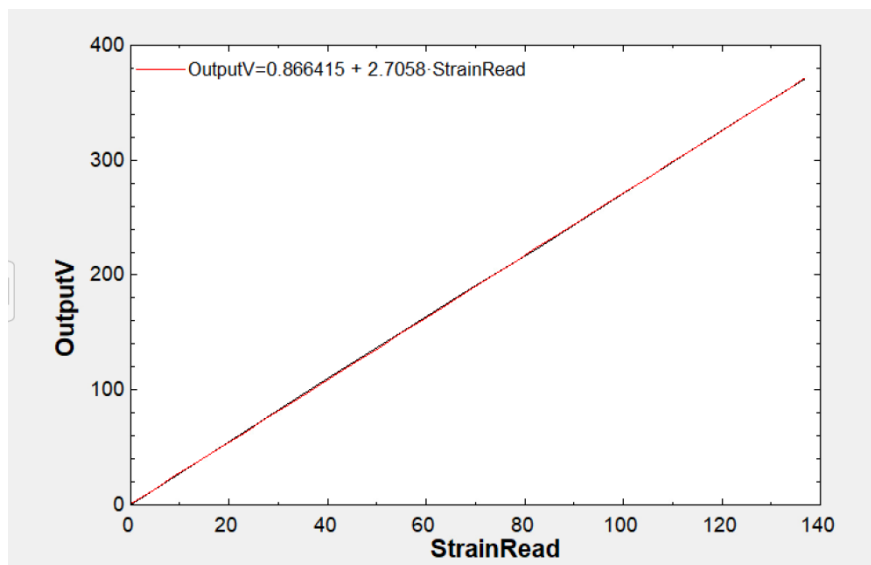


Figure 3.1 OutputV vs StrainReading for Quarter Bridge

Discussion: In this graph shows that we have a positive slope of strain and output in V that was displayed during the experiment. The y-axis of the graph measures the output V. The x-axis measures the Strain Read. We analyzed in this graph the liner relationship between both variables represented in the above by using the curve fit in the EES program we can have more accuracy for each of the points given in the data. Having a result of a positive slope with 2.70 every time when the Strain Read increased the output would therefore increase.

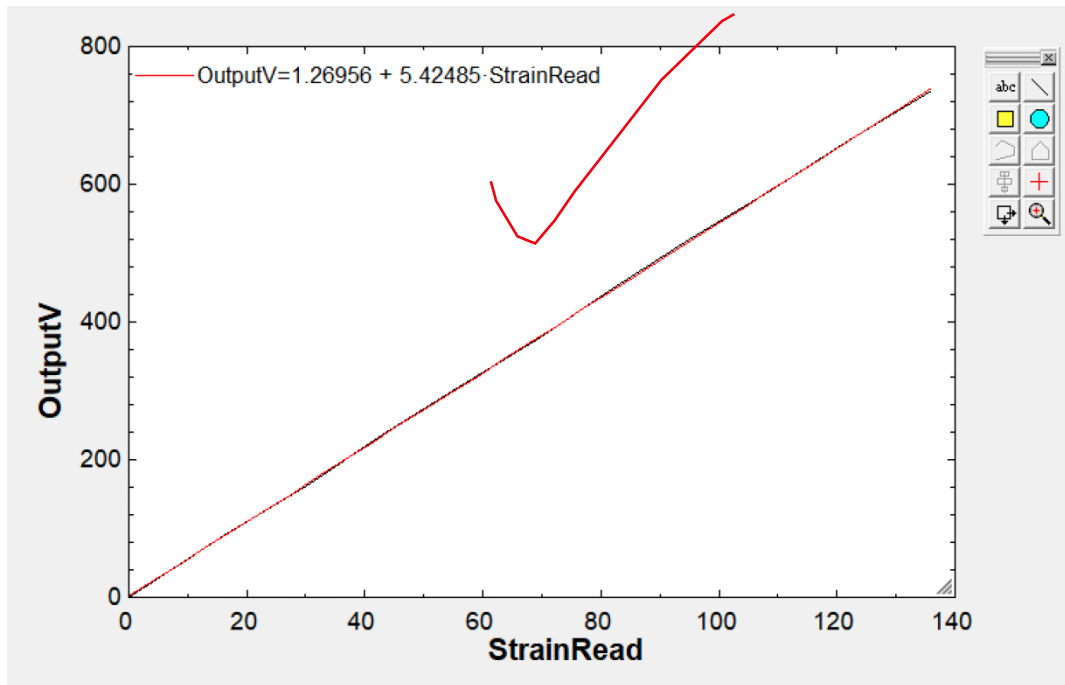


Figure 3.2 OutputV vs StrainRead for Half Bridge 1

Discussion: In this graph we have in the vertical axis the output in V and in the horizontal axis we have the Strain Reading in that we see in the apparatus used in the lab. We analyzed in this graph the linear relationship between both of the variable represented in the above by using the curve fit in the EES program we can have more accuracy for each of the points given in the data. Having a result of a positive slope with 5.42 every time when the Strain Read increased the output would therefore increase.

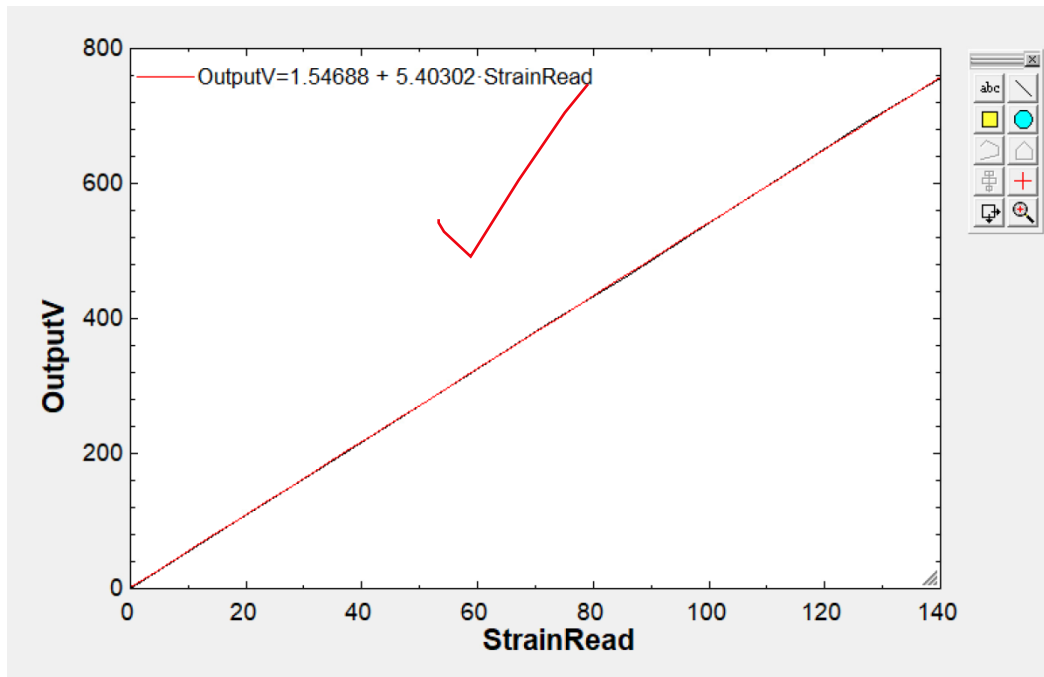


Figure 3.3 OutputV vs StrainRead for Half Bridge 2

Discussion: In this graph we have measured in the horizontal axis the StrainRead while in the vertical we can measure the Output V. We analyzed in this graph the linear relationship between both variables represented in the above by using the curve fit in the EES program we can have more accuracy for each of the points given in the data. Having a result of a positive slope with 5.40 every time when the Strain Read increased the output would therefore increase. The difference between half bridge 1 and 2 is therefore slightly different the first half bridge has a slope of 5.42 while the second has a 5.40. Both bridges have a still positive linear relationship.

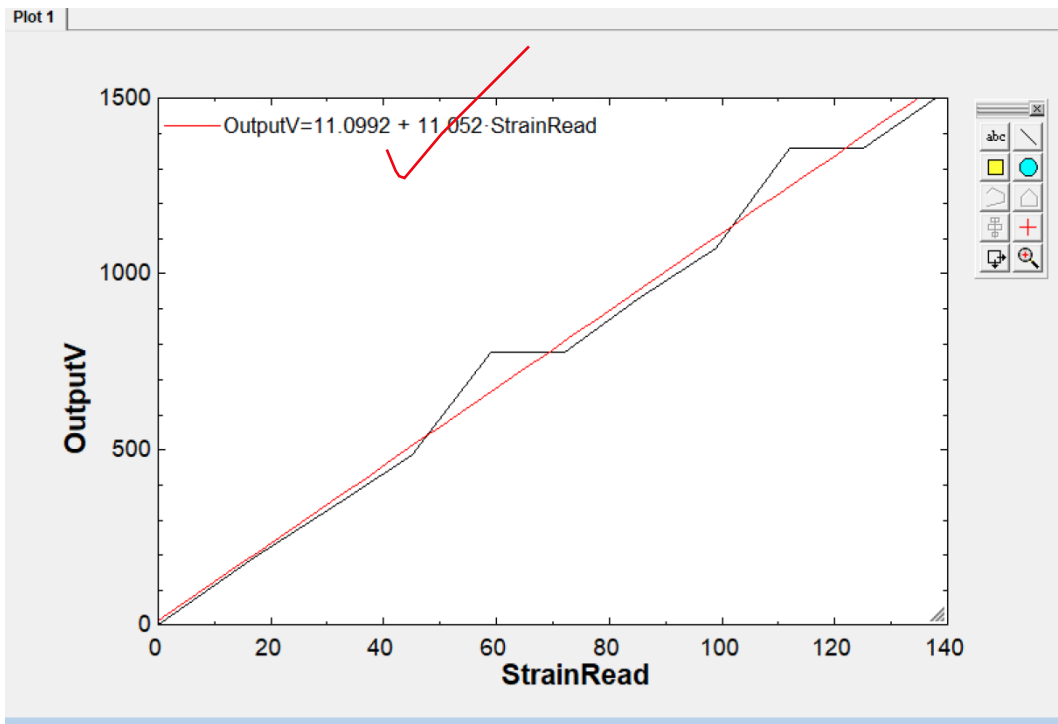


Figure 3.4 OutputV vs StrainRead for full bridge.

Discussion: In this graph we have measured in the horizontal axis the StrainRead while in the vertical we can measure the Output V. We analyze in this graph the changes in the linear relationship compared to the half bridge 1,2 and the quarter bridge. The full bridge has a higher slope of 11.052 which makes a distortion in the linear relationship. Using the curve fit through EES we can still see the accuracy of the data calculated in the parametric table using with the coding to calculate the strain for the full bridge. Each point was taken from the parametric table to create the equation that resulted from curve fit.

3.2 Conclusions based on each Objective and Results

Using the Engineering Equation Solver, we were able to conduct statistical analysis to solve different types of equations to determine strain measurement. The primary difference between EES and Excel is that you can identify the variable and the equation to necessary compute functions before you create the table, on the other hand excel you can create a table as you proceed while computing the necessary function and identifying different variables. The purpose of this lab was to understand the theory of strain gauges by doing to physical lab and analyze the data given in the lab through EES. Moreover, to show the equation used by the strain display, and to show and compare different strain bridge connections and show the linearity of strain measurement. We noticed in the graph represented by the equation calculated in EES that the Output V and the Strain Reading have a linear relationship and when one increases the other variable would also increase. Also, the calculated strain and the reading strain are slightly different and have almost the same results making the results have a positive value in a linear relationship.

3.3 Recommendations- I learned to use the program EES which easily gave us the solved tables using the right pattern of coding. It also shown the accuracy that the program is and can give us wide information analytical towards different aspects of the experiment. Lab 5 was a great example of how to calculate the strain and how weight affect the bending moment in the object.

AVERAGE

**MECHANICAL ENGINEERING DEPARTMENT
PRAIRIE VIEW A&M UNIVERSITY**



MCEG 3101 MEASUREMENT LABORATORY

Fall 2021 Section P01

LABORATORY REPORT ON

**“STRAIN MEASUREMENT USING STRAIN GAUGE
AND THE WHEATSTONE BRIDGE”**

**Conducted on
August 24, 2021**

**Submitted by
Christopher Nweke**

**On
December 7, 2021**

To

**Dr. Mingli Han
*Measurement Laboratory Instructor***

**MECHANICAL ENGINEERING DEPARTMENT
MEASUREMENT LABORATORY GRADING SHEET
FALL 2021 SECTION P01**

Title of Experiment: _____

Name: _____

Date Lab was Performed: _____ **Report Due Date:** _____

<i>Ability to Conduct Experiments</i>	MAX	Your Score	Comments
Ability to demonstrate general lab safety (by your conduct and observations).	3	3	
Ability to follow the procedure and properly rephrasing the procedure to reflect what you did during the experiment.	7	7	
Ability to demonstrate knowledge of how equipment function, their limitations, and the uncertainty associated with reading the instruments.	5	5	
Ability to collect and record the raw data using appropriate units of measurement and identify the dependent and independent variables in the experiment.	5	5	
Total for Ability to Conduct Experiments	20		
Percentage for this Performance Criteria			
<i>Ability to Analyze and Interpret experimental Data in a Formal Report</i>			
Report format (Ability to properly format and present a technical report)	13	9	
Provides appropriate abstracts for the experimental report	5	3	
Ability to analyze the data using appropriate software to generate the required parameters using consistent units	27	23	
Ability to present the data (raw /derived) in tabular and graphical form to meet the objectives and to aid in interpretation.	14	12	
Ability to discuss the raw and derived data/graphs and assess the validity of the results in relation to the underlying theory and expected trends.	14	12	
Ability to draw appropriate and reasonable conclusions in relations to each of the experimental objectives. One conclusion statement for each objective.	7	7	
Total for Ability to Analyze and Interpret experimental Data	80		
TOTAL FOR THIS LAB		86	

Letter of Transmittal

Christopher Nweke
Mechanical Engineering Student
8505 Barron Wood Circle East
Cell:7134174629
Cnweke1@pvamu.edu

Dr. Mingli Han
Measurements Laboratory
Prairie View A&M
S.R Collins Engineering Technology Building
Room 311

Dear Dr. Han

The following pages are a detailed report for lab 5 of MCEG Measurement and Instrumentation Laboratory, “Strain measurements”. This report addresses the use of a sonar sensor used to collect data using sonar sensors. Theory of strain gauges and its application To show the equation used by the strain display We will utilize EES to determine the calibration and organize and plot data and equation using a curve fit, tables and code. The lab is due December 10th, 2021, if you have any questions or concerns, please call or email me at any time.

Sincerely,
Christopher Nweke

Abstract

The purpose of this lab experiment was to learn how to utilize EES in order to solve an engineering problem. The purpose of this experiment is to understand and analyze strain measurements shown in this lab. We will utilize coding programs within EES to find critical values understanding strain gauges and analyze variables such as voltage Gauge Factor, Fixed Input Voltage applied to the bridge (V), Number of active arms (gauges connected), $\mu\epsilon$ (micro strain).

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Chapter 1 Ability To Conduct Experiments

Chapter 1.1 Objective:

To understand the theory of strain gauges and its application.

To show the equation used by the strain display. Final objective is to show and compare different strain bridge connections and show the linearity of strain measurement

1.2 Theory

Theory:

1. Strain Gauges

Strain Gauges are electrical sensors (transducers) that measure strains. Their electrical resistance changes by a small amount when an external force stretches or compresses them. This change in resistance is directly proportional to displacement (strain).

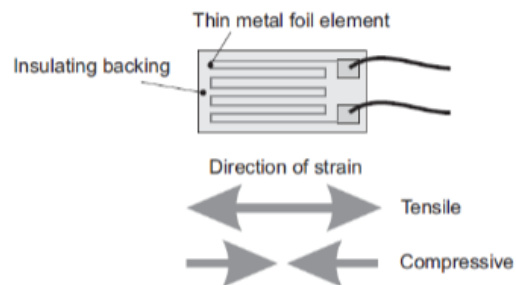


Figure 1.1 Simplified diagram of a strain gauge

1.1

Strain gauges are small sheets of metal foil cut in a zigzag pattern. Figure 1 shows a simplified and enlarged version, Figure 2 shows a more realistic but enlarged drawing of a common strain gauge. They are only a few microns thick. Thus, for mechanical stability and electrical insulation, they are normally mounted on a backing sheet. The user bonds the gauges to the surface of the structural part under examination. The strain gauge stretches and compresses with the surface of the part that they are stuck to. Note that a negative strain reading is a compressive strain and a positive reading is a tensile strain.

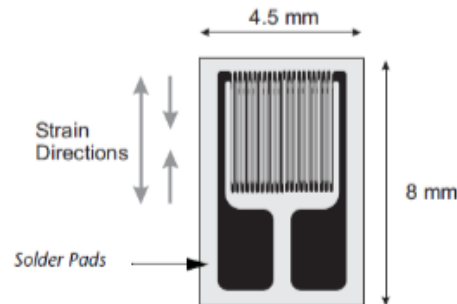


Figure 2 Enlarged and more realistic view of a common strain gauge

You must use a strain gauge in the right direction. It only works correctly when it measures strain in line with the elements of the gauge (see Figure 1). Strain gauges only give a very small resistance change (or no change at all) to strains that are not in line with the elements.

To give a direct reading of strain, instruments multiply the reading from a strain gauge by a constant called the **gauge factor**. The gauge factor is a measure of the strain gauges sensitivity to strain and varies slightly between different batches of the foil used to make the gauges. The gauge factor for standard metallic foil gauges usually varies between 1.9 and 2.3 for each batch.

Because strain gauges are made of thin strips of foil, their sensitivity to temperature (resistance change) is higher than a normal electrical wire conductor. Normally, their resistance increases as their temperature rises. Therefore, for reliable results where temperatures will change, engineers usually add temperature compensation to any circuit that includes the strain gauge.

2. Strain Gauge Rosettes

2. Strain Gauge Rosettes

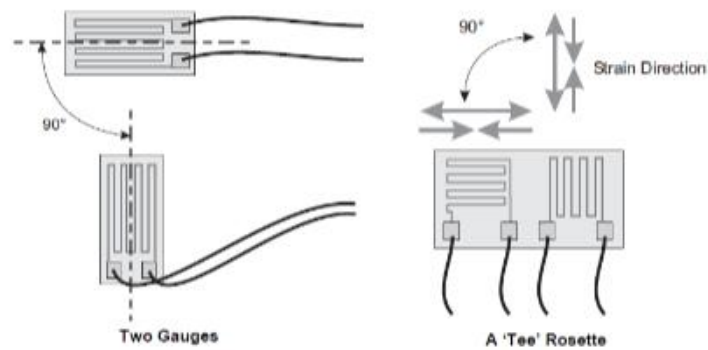


Figure 3 Two gauges at 90 degrees to each other and a 'T' rosette

When you need to measure strain in two or more different directions (at angles to each other), you can simply add extra strain gauges near to each other. However, strain gauges are usually very small and getting the angle right is difficult, so strain gauges can be bought as 'rosettes'. A rosette has two or more gauges already bonded to a backing material. Each gauge is accurately positioned by machines. This can save time and give more accurate and reliable readings. The Torsion System of the Strain Gauge Trainer has a bar that twists, so its stress and strain is actually at 45 degrees to the length of the bar. Special rosettes of two gauges at 45 degrees as shown in Figure 4 measure this strain.

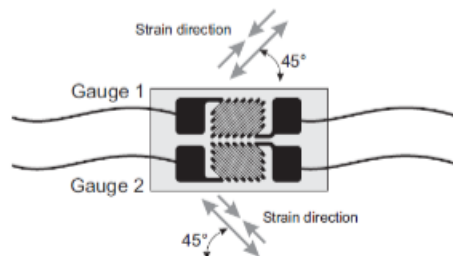


Figure 4 Shear and torque gauge rosette

3. The Wheatstone Bridge

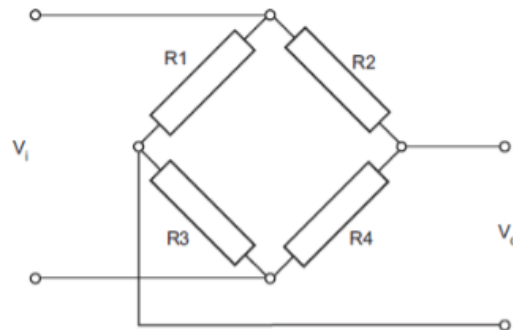


Figure 5 The Wheatstone Bridge

The basis of most strain measurement is the Wheatstone Bridge, shown in Figure 5. It has four identical resistance (R_1 , R_2 , R_3 and R_4) connected end to end in a diamond shape. An input voltage (V_i) connects two opposite connections. The output voltage is measured at the other two connections.

The output voltage (V_o) depends on the ratio of the resistors, so that:

$$V_o = V_i \frac{R_4}{R_2 + R_4} - V_i \frac{R_3}{R_1 + R_3} \text{ or } V_o = V_i \left(\frac{R_4}{R_2 + R_4} - \frac{R_3}{R_1 + R_3} \right)$$

As the equation shows, when R_1 , R_2 , R_3 and R_4 are all exactly equal, then the output voltage V_o is zero, no matter what happens to the input voltage V_i . However, if one resistance changes (for example, R_1), then V_o will change in proportion to the resistance change.

The Quarter Bridge Connection

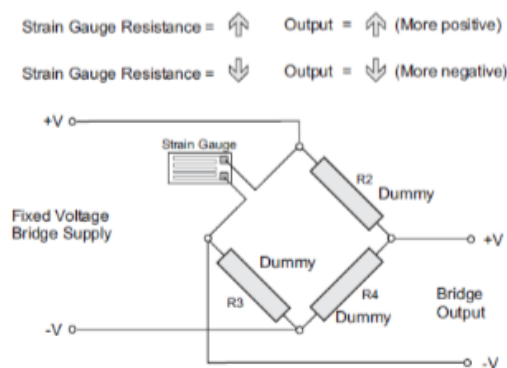


Figure 6 Quarter bridge connection – one active strain gauge

When a single strain gauge replaces one of the resistors, the output voltage V_o is proportional to the strain in the gauge. This is the **Quarter Bridge** connection (see Figure 6). When all resistors are equal, the output potential difference is zero. As the strain gauge resistance

increases (tensile strain), the output potential difference becomes more positive. As the strain gauge resistance decreases (compressive strain), the output potential difference becomes more negative.

Note that resistors R2, R3 and R4 are 'dummy' or 'make-up' resistors, matched to have exactly the same resistance as the unstressed strain gauge. This is a simple circuit and has no temperature compensation. The output from the bridge is not perfectly linear, but for normal resistance changes, the output is assumed to be linear.

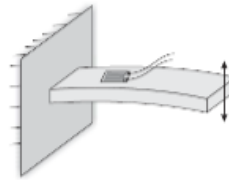


Figure 7 Application of a Quarter Bridge Strain Gauge

Half Bridge 1 (Opposite Arms)

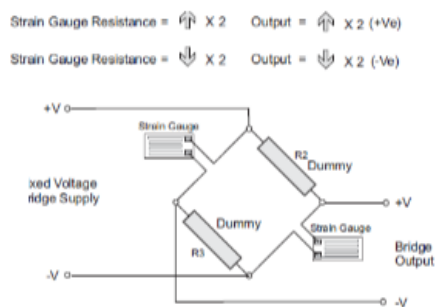


Figure 8 Half Bridge (opposite) connection

If the resistance of R1 and its opposite resistor (R4) both increase by the same amount, the output voltage changes twice as much as if only one resistor changes. This shows that you can get more output and therefore higher sensitivity if you use two identical strain gauges together. This connection is the **Half Bridge**, shown in Figure 8. Each gauge is opposite to the other, so both gauges must measure the same strain, so that they both change resistance in the same way (for example, both increases in resistance). Thus, two opposing gauges must measure the same type of strain (tensile or compressive) at the same place on the test structure. Note that this connection uses two dummy resistors, matched to have the same resistance as the gauges. The output from the bridge is not perfectly linear, but better than a quarter bridge. For normal strain gauge resistance changes, the output is assumed to be linear.

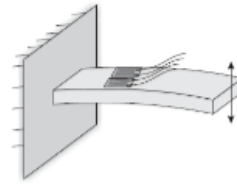


Figure 9 Application of an Opposite Half Bridge Strain Gauge

Half Bridge 2 (Adjacent Arms)

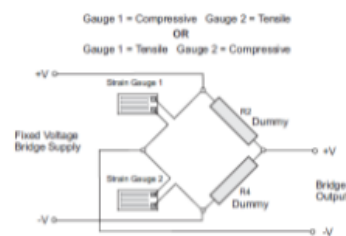


Figure 10 Half Bridge (adjacent) Connection

Figure 10 shows a half bridge connection with two adjacent strain gauges. In this case the changes in the strain gauge resistances will cancel out each other, so they must measure identical but opposite strains on the same part of the structure under test. One gauges must measure compressive strain and the other must measure tensile strain (or the opposite way around). When used in this way, this bridge will also give twice as much output as a quarter bridge. When both strains are equal in magnitude, the output from the bridge is almost linear.

Alternatively, one gauge can be fixed near to the other, but a place where there is no strain, but both gauges are always at the same temperature. This gauge will not measure strain, so the output is similar to the quarter bridge, but it will help to cancel any effects of temperature change. Again, the resistors are dummies, matched to the strain gauges.

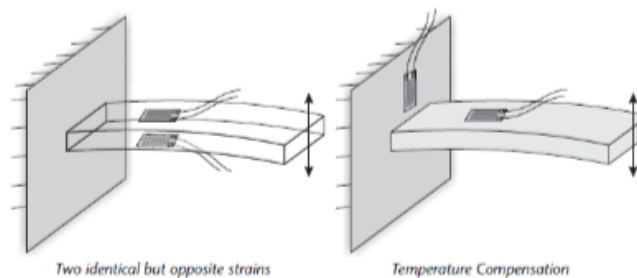


Figure 11 Application of the Adjacent Half Bridge Strain Gauge

Full Bridge

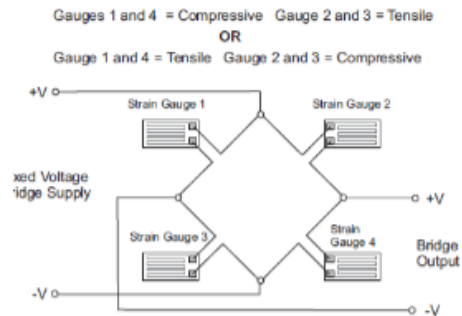


Figure 12 Full Bridge Connection

Figure 12 shows a **Full Bridge** connection, where four strain gauges form the bridge. This bridge gives twice as much voltage output and sensitivity than the standard half bridge (and four times the output of a quarter bridge). As in the half bridge, each opposite gauge must measure the same type of strain and the other two opposing gauges must measure the opposite type of strain on the same part of the structure. For example, gauges 1 and 4 must measure tensile strain, while gauges 2 and 3 must measure compressive strain, or the other way around. When all strains are equal in magnitude, the output from the bridge is linear.

Alternatively, two adjacent gauges (for example 2 and 4) can be fixed near to the other gauges, but at a place where there is no strain, but all gauges are always at the same temperature. These gauges will not measure any strain, so the output will be similar to the half bridge, but they will help to cancel out any effects of temperature change.

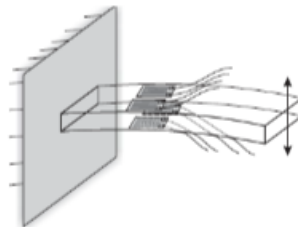


Figure 13 Application of Full Bridge Strain Gauge

4. Strain Bridge Equation

To calculate the strain from the dc voltage across the bridge, the Strain Display uses a standard equation:

$$\epsilon = 4 \times \frac{V_o}{GF \times V_i \times N} \quad (1)$$

Where

ϵ = Strain

V_o = Voltage measured across the bridge (V)

GF = Gauge Factor

V_i = Fixed Input Voltage applied to the bridge (V)

N = Number of active arms (gauges connected)

The output is then multiplied by 10^6 to give a result in $\mu\epsilon$ (micro strain)

Chapter 1.4 Apparatus

The equipment for this experiment is the strain gauge trainer shown in Figure 14.

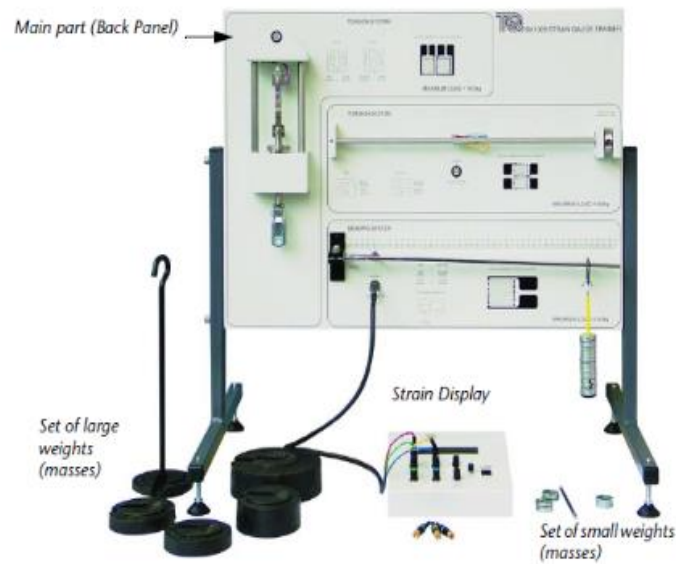


Figure 14 The strain gauge trainer

It contains the tension system, the torsion system and the bending system. The Bending System is a solid, rectangular section cantilever beam. This is a specimen beam held securely at one end. It simulates many different mechanical and constructional things such as: aeroplane wings, swimming pool diving boards, bridges, balcony supports on buildings, and shelf supports. A secure clamp holds the specimen beam at one end. A cantilever can bend or 'deflect' upwards or downwards, this experiment bends the beam downwards. Four standard strain gauges measure the tensile and compressive strains directly in line with the beam. Two gauges measure the tensile strain on the top of the beam. The other two gauges measure the compressive strain underneath the beam.

The strain display shown in Figure 15 is a metal box with a display, controls and input sockets. The input sockets accept the signals from the color-coded gauges on the three different systems of the Strain Gauge Trainer. The multiline display shows the output voltage measured across the strain bridge and automatically calculates and displays the strain. You set the Strain Display to match your chosen strain gauge connections and their gauge factor. Supplied with the equipment are special plugs with built-in high precision dummy resistors, for use when you only measure one or two active arms (gauges). The gauge factor control allows the user to set the gauge factor of the strain gauge that they connect to. A zero button allows the user to zero (or null) the readings before each experiment. The display uses the voltage output from the gauges to calculate the strain. A configuration switch changes the calculations of the Strain Display, so that it shows the correct strain for any bridge connection.

Chapter 1.5 Procedure

Procedure:

1. Create four blank results tables, each similar to Table 1.
2. Connect the strain connection cable to the output socket of the Bending System.

1.6 Raw Data

Quarter Bridge		Active arm: 1	
Load position: 420mm		Gauge factor: 2.16	
Load (g)	Strain Reading ($\mu\epsilon$)	Output (μV)	Calculated strain ($\mu\epsilon$)
0	0	0	
50	13	36	
100	27	74	
150	40	110	
200	55	150	
250	69	188	
300	83	225	
350	97	263	
400	109	296	
450	123	334	
500	137	371	

Half Bridge 1 (Opposite Arm)		Active arm: 2	
Load position: 420mm		Gauge factor: 2.16	
Load (g)	Strain Reading ($\mu\epsilon$)	Output (μV)	Calculated strain ($\mu\epsilon$)
0	0	0	
50	16	90	
100	30	162	
150	43	235	
200	56	306	
250	69	374	
300	82	447	
350	95	519	
400	109	592	
450	122	664	
500	136	737	

Half Bridge 2 (Adjacent Arm)		Active arm: 2	
Load position: 420mm		Gauge factor: 2.16	
Load (g)	Strain Reading ($\mu\epsilon$)	Output (μV)	Calculated strain ($\mu\epsilon$)
0	0	0	
50	16	89	
100	31	169	
150	45	245	
200	59	320	
250	72	392	
300	86	465	
350	100	542	
400	113	613	
450	127	690	
500	140	755	

Full Bridge		Active arm: 4	
Load position: 420mm		Gauge factor: 2.16	
Load (g)	Strain Reading ($\mu\epsilon$)	Output (μV)	Calculated strain ($\mu\epsilon$)
0	0	0	
50	17	190	
100	34	367	
150	45	485	
200	59	778	
250	72	778	
300	85	925	
350	99	1072	
400	112	1357	
450	125	1387	
500	138	2500	

In the tables above are the raw data values for the lab. The top two tables are called quarter bridge and half bridge. We are given the assignment to document calculated strain. With a gauge factor of 2.16. The bottom two tables are half bridge and full bridge.

2.1 Detailed computer analysis

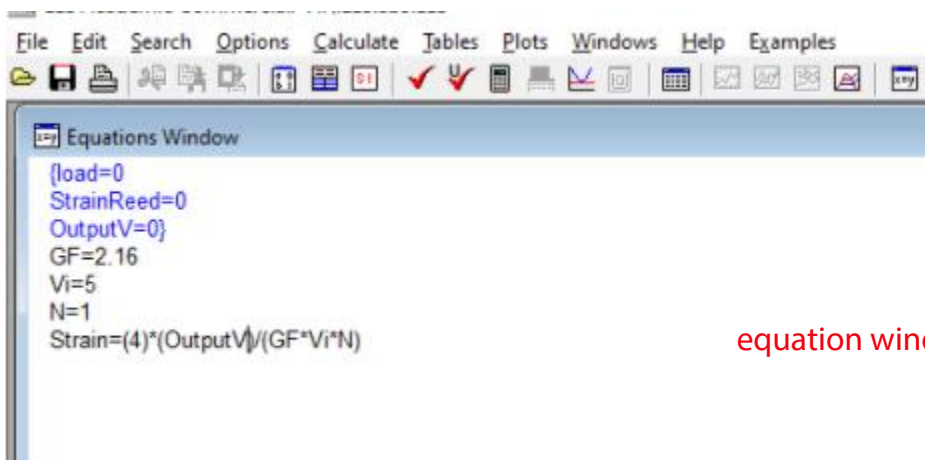
Table 2.1

1.21	1 G	2 ue	3 uv	4 e
Run 1	0	0	0	0
Run 2	50	13	36	13.3
Run 3	100	27	74	27.41
Run 4	150	40	110	40.7
Run 5	200	55	150	55.9
Run 6	250	69	188	69.62
Run 7	300	83	225	83.3
Run 8	350	97	263	97.41
Run 9	400	109	296	109.6
Run 10	450	123	334	123.7
Run 11	500	137	371	137.4
Run 12				

In the table above we utilize EES in order to solve strain equations. Based on the data given we come to analyze that our ue column is very close in value to our e strain values.

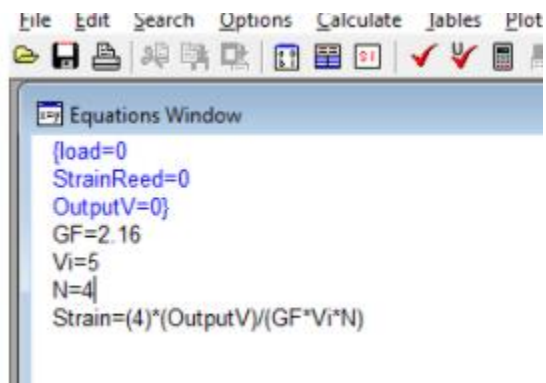
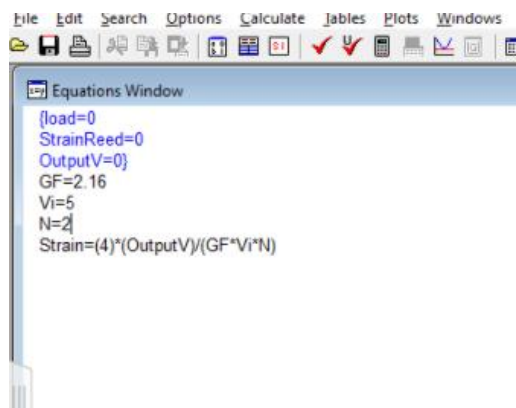
$4 \frac{Vo}{GF*Vi**N}$ = to strain values. This equation was used to compute values in all four tables.

2.2 Presentation of Derived results



equation window should be in 2.1 section

Code from EES software the code from all four tables are similar however they are slightly different from each table. The N values will consistently change but our GF will always equal 2.16 Vi value was set at 5 volts in this experiment.



Photos purpose is to display coding programs used for derived values in multiple tables in lab 6.

Table 2.2

caption?

EES Academic Commercial: H:\EES labatory 5.EES - [Parametric Table]

File Edit Search Options Calculate Tables Plots Windows Help E

Table 1 Table 2

	1	2	3	4
	G	Ue	uV	e
Run 1	0	0	0	0
Run 2	50	16	90	16.6
Run 3	100	30	162	30
Run 4	150	43	235	14.52
Run 5	200	56	306	56.6
Run 6	250	69	374	69.26
Run 7	300	82	447	82.7
Run 8	350	95	519	96.1
Run 9	400	109	592	109.6
Run 10	450	122	664	123
Run 11	500	136	737	136.5

In the table above we have values our G column will repeat over again in all four tables we will also notice similar patterns from table one with correlation of the e and ue column. After computation in e columns the values are very close to ue values in all of our tables. Code to tables the N value will change constantly through the code for tables. The reason being is because our active arms change per table but the G column will increase at the same rate.

Table 2.3

Table 1 Table 2 Table 3				
1.11	1 G	2 Ue	3 uV	4 e
Run 1	0	0	0	0
Run 2	50	16	89	16.48
Run 3	100	31	169	31.2
Run 4	150	45	245	45.37
Run 5	200	59	320	59.26
Run 6	250	72	392	72.59
Run 7	300	86	465	86.1
Run 8	350	100	542	100.4
Run 9	400	113	613	113.5
Run 10	450	127	690	127.7
Run 11	500	140	755	139.8

Table 2.4

	1	2	3	4
	G	U _e	uV	e
Run 1	0	0	0	0
Run 2	50	17	190	17.59
Run 3	100	34	367	33.9
Run 4	150	45	485	44.91
Run 5	200	59	778	72.04
Run 6	250	72	778	72.04
Run 7	300	85	925	85.64
Run 8	350	99	1072	99.26
Run 9	400	112	1357	125.6
Run 10	450	125	1357	125.6
Run 11	500	138	1500	138.8

In code and tables above code 1 through 4 is provided and also table 1-4 is provided data is not exactly the same but similar correlations appear in all four tables.

Chapter 3

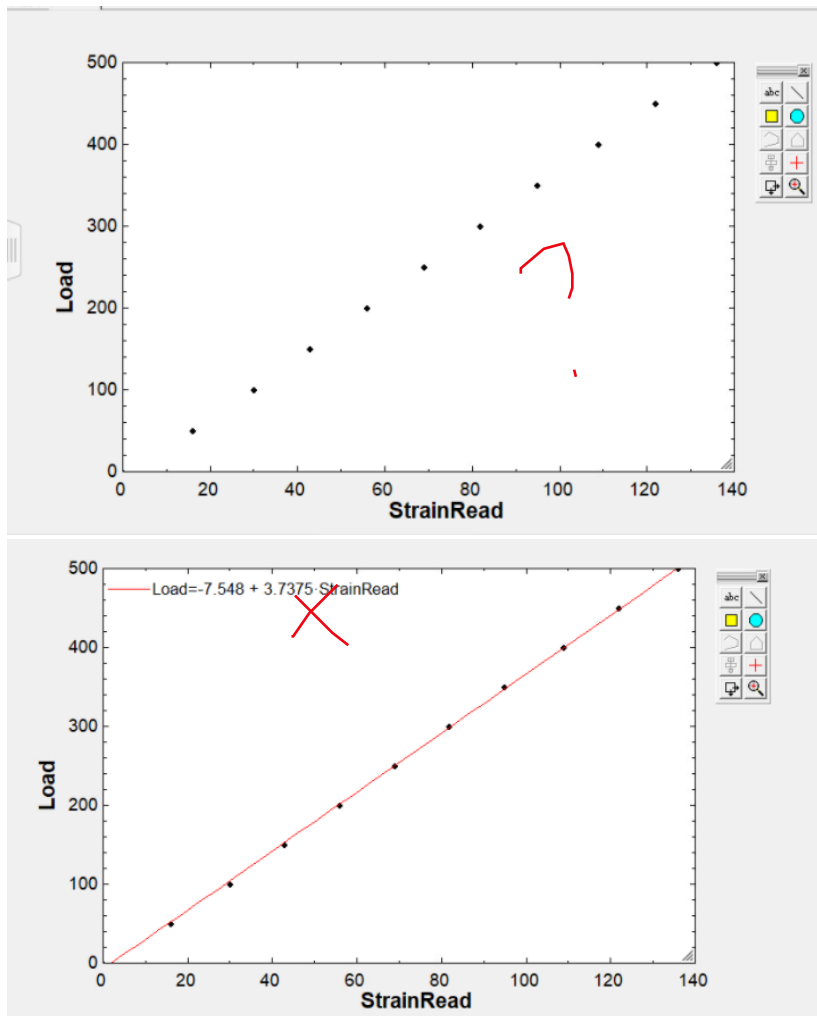


Figure 2.2

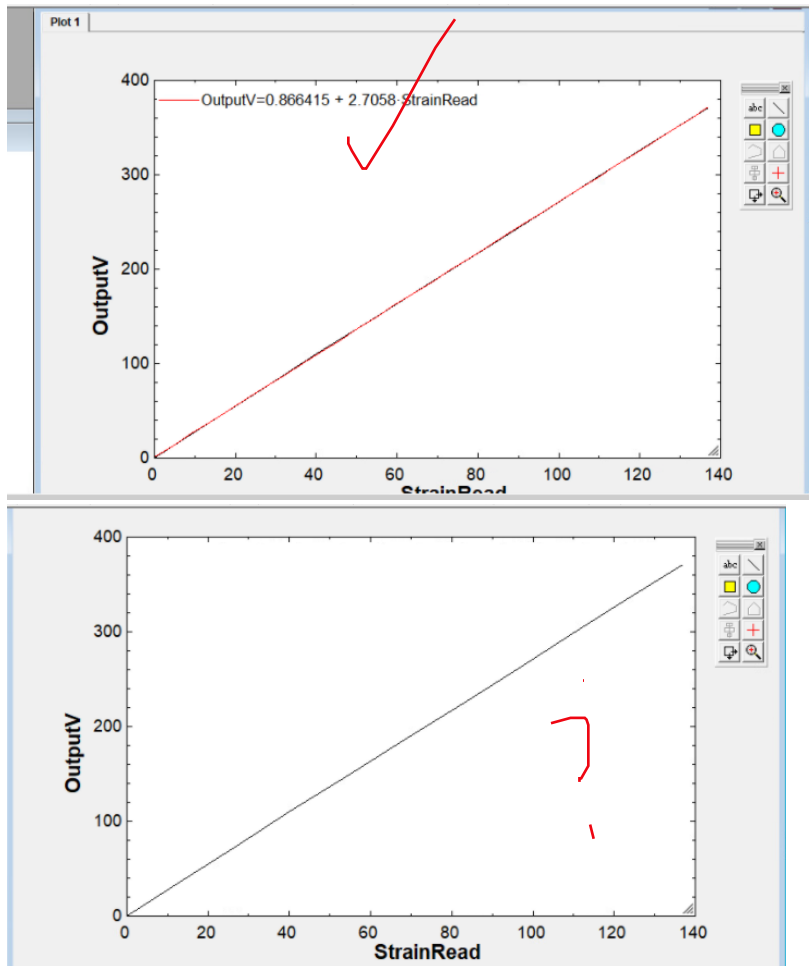


Figure 2.3

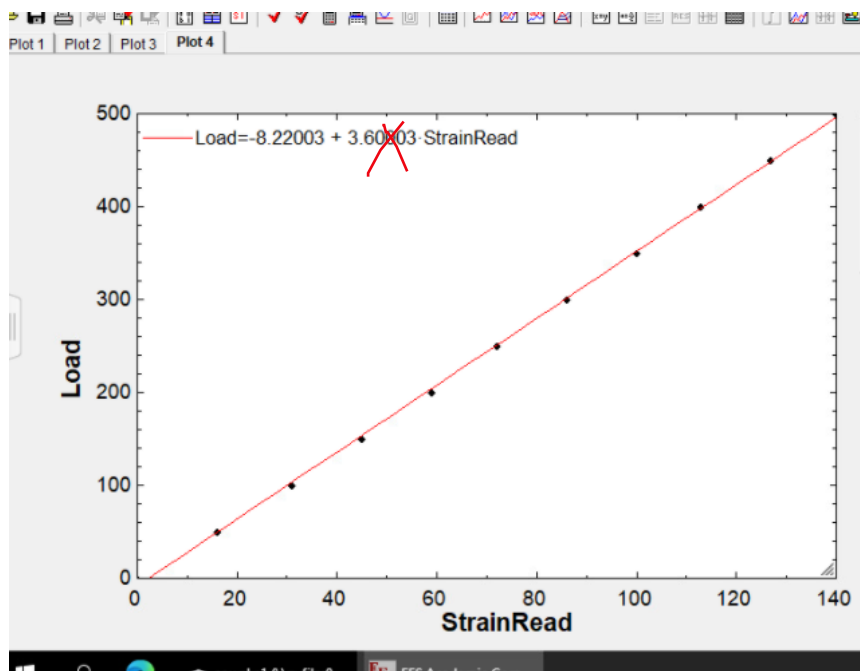
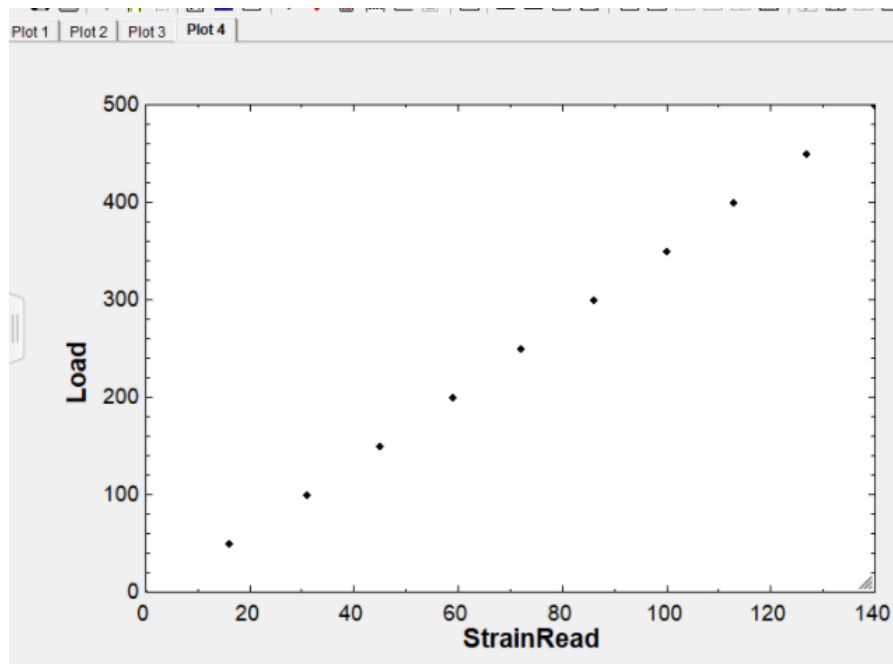


Figure 2.4

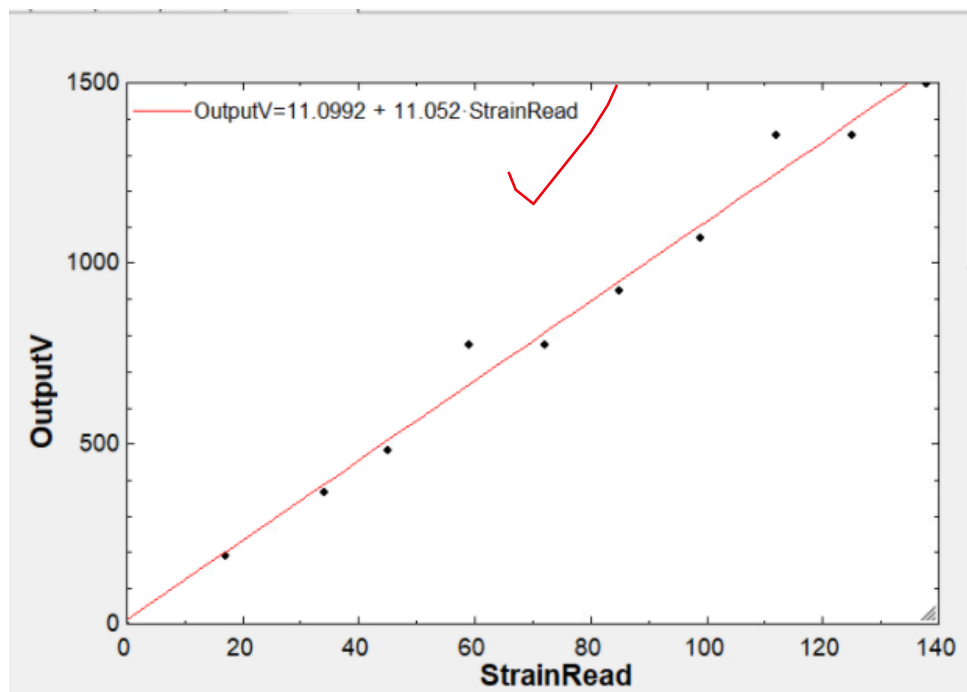
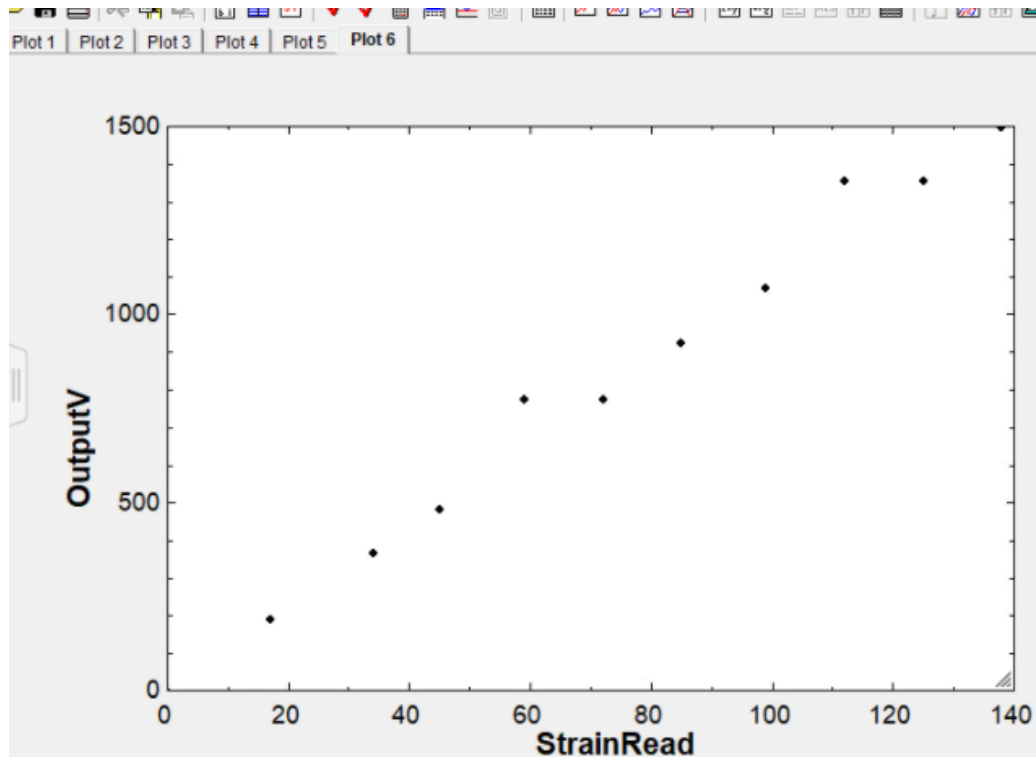


Figure 2.4

Based on the tables listed above we find that there is connection to strain and output voltage as strain increased our output increased there proportional although slope and curve fit of all tables are different from each other. We also noticed on table four there is a subtle inflection in strain read values different from the other tables however the strain and output relation will remain the same.

3.1 Presentation of Graphs/figures and interpretation of results by graph

3.2 Conclusion

In conclusion, we successfully conducted lab in team groups and as well as documented critical values in lab 5. We observed and analyzed the most vital parts of this lab such as understanding the theory of strain gauges and its application. Show the equation used by the strain display and final objective is to show and compare different strain bridge connections and show the linearity of strain measurement.

3.3 Recommendations:

I have learned how to compute values in EES as well as how to use EES. Prior to this lab I have experimented with software but software is much simpler than other software's that are much more intensive.

BELOW AVERAGE

**MECHANICAL ENGINEERING DEPARTMENT
PRAIRIE VIEW A&M UNIVERSITY**



MCEG 3101 MEASUREMENT LABORATORY

Fall 2021 Section P01

LABORATORY REPORT ON

Strain Measurement Data

**Conducted on
November 24, 2021**

Submitted by

**On
November 30 , 2021**

To

**Dr. Mingli Han
*Measurement Laboratory Instructor***

**MECHANICAL ENGINEERING DEPARTMENT
MEASUREMENT LABORATORY GRADING SHEET
FALL 2021 SECTION P01**

Title of Experiment: _____

Name: _____

Date Lab was Performed: _____ **Report Due Date:** _____

<i>Ability to Conduct Experiments</i>	MAX	Your Score	Comments
Ability to demonstrate general lab safety (by your conduct and observations).	3	3	
Ability to follow the procedure and properly rephrasing the procedure to reflect what you did during the experiment.	7	7	
Ability to demonstrate knowledge of how equipment function, their limitations, and the uncertainty associated with reading the instruments.	5	5	
Ability to collect and record the raw data using appropriate units of measurement and identify the dependent and independent variables in the experiment.	5	5	
Total for Ability to Conduct Experiments	20		
Percentage for this Performance Criteria			
<i>Ability to Analyze and Interpret experimental Data in a Formal Report</i>			
Report format (Ability to properly format and present a technical report)	13	6	
Provides appropriate abstracts for the experimental report	5	4	
Ability to analyze the data using appropriate software to generate the required parameters using consistent units	27	5	
Ability to present the data (raw /derived) in tabular and graphical form to meet the objectives and to aid in interpretation.	14	7	
Ability to discuss the raw and derived data/graphs and assess the validity of the results in relation to the underlying theory and expected trends.	14	12	
Ability to draw appropriate and reasonable conclusions in relations to each of the experimental objectives. One conclusion statement for each objective.	7	4	
Total for Ability to Analyze and Interpret experimental Data	80		
TOTAL FOR THIS LAB		58	

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Abstract

As the name suggests, strain gauge measures stress via changing electrical resistance which changes when they are compressed or stretched. This change in resistance represents the strain produced. In short, we can say that they are electrical sensors or transducers. The experiment showed that as the strain goes up the output voltage goes up also. This is in accordance with the theory of the strain gauges. The only difference is that the Quarter Bridge produces less voltage as compared to the half bridges of both types. The full bridge acts in the same way as the half bridge, the only advantage is that that it can also describe the two types of strains produced simultaneously. One can say that the half bridge is much affective than its counter parts as it is more sensitive and provide twice the output. But it cannot provide the clear info about the direction of strain. For that one can use full bridge configuration and can observe the strains in both directions.

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Chapter 1. Conducting Experiment

1.1 Objectives of the Experiment

- To be able to comprehend the theory of strain gauges and its applications.
- Represent the equation used by strain gauges.
- Study and analyze different strain gauge connections show linearity of strain measurement.

1.2 Theory

1.2.1 Strain Gauge

As the name suggests, strain gauge measures stress via changing electrical resistance which changes when they are compressed or stretched. This change in resistance represents the strain produced. In short, we can say that they are electrical sensors or transducers.

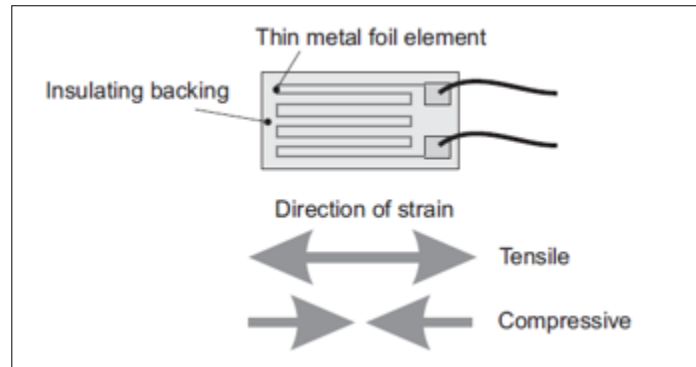


Figure 1-Strain gauge diagram

Strain gauge consists of thin metal sheets which are only few microns thick. Due to their fragility and to provide stability and insulation, they are mounted on a support material which is an insulating material. The gauges are connected to the surface whose strain measurement is required as shown in the above figure. The produced strain causes the resistance to change which ultimately produces required strain measurement. Note that negative reading represents compression while positive reading shows a tensile strain.

One thing should be paid attention to, is that the strain gauge must be placed in line with the direction of produced strain as shown in the above figure. If the strain gauge is not in line with the produced strain, then the strain gauge would show a slight disturbance or no reading at all. Hence it is important to analyze the experimental set up in order to obtain the best possible results.

Another thing noteworthy is that strain gauges are more sensitive to temperature than any other metallic strip because they are made of very thin metallic sheets. Their resistance increases with the temperature and can cause the reading to be dubious one. Hence, places where there is significant temperature rise and gradient, engineers provide either additional insulation or a compensation factor is introduced.

1.2.2 Strain Gauge Rosettes

When the strains in different direction is to be measured or at right angles, two strain gauges can be placed in those directions making the same angle as the strains make. However, to get the angles

right is very difficult task and also time consuming. To avoid this hectic task, strain gauges can be bought as rosettes which are specially designed for these kinds of situations. The angles are calibrated by machines precisely in the same way as the stress angles. The following figure shows the concept of strain gauge rosettes.

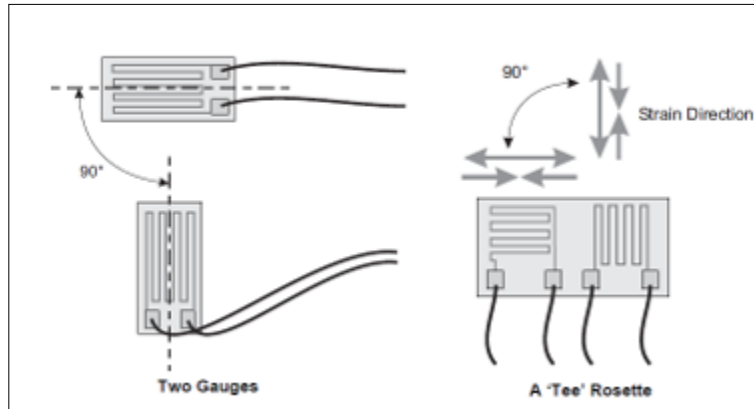


Figure 2-Strain Gauge Rosettes

1.2.3 Wheatstone Bridge

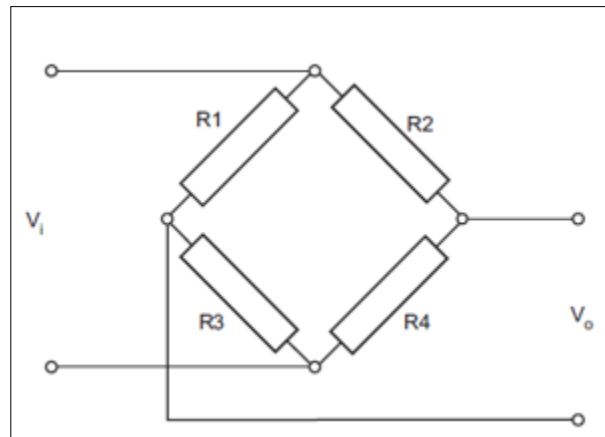


Figure 3-Wheatstone bridge

Wheatstone bridge forms the basis of the strain measurements. It has four identical resistances connected end to end. The input voltage is measured at one end and the output voltage at the other end as shown in figure with V_i and V_o respectively. The ratio of resistors is shown in the following equation which represents the output voltage:

$$V_o = V_i \frac{R4}{R2 + R4} - V_i \frac{R3}{R1 + R3} \text{ or } V_o = V_i \left(\frac{R4}{R2 + R4} - \frac{R3}{R1 + R3} \right)$$

1.2.3.1 Quarter Bridge Connection

Quarter bridge connection is defined as when a single strain gauge is replaced with any of the resistances in the bridge, the output voltage shows the strain produced. It is shown schematically in the following figure:

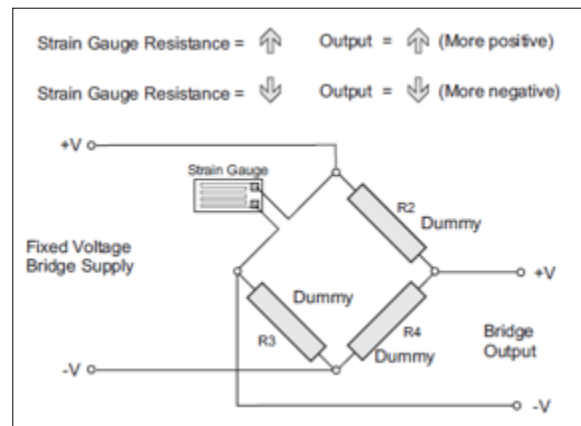


Figure 4-Quarter Bridge Connection

The output potential would show zero reading when all the resistances are equal. One thing to notice here is that the other resistors should have the same resistance as the unstressed strain gauge. The trend shown is such that when the strain gauge resistance increases, the output potential becomes more positive and vice versa.

1.2.3.2 Half bridge 1 (Opposite arms)

This setup allows more sensitive reading of the output voltage. When two opposite resistances are increased by the same amount, the output voltage is twice as much as when the single resistor is increased. This helps in more precise and accurate reading when both strain gauges are of same magnitude. The schematic is shown below:

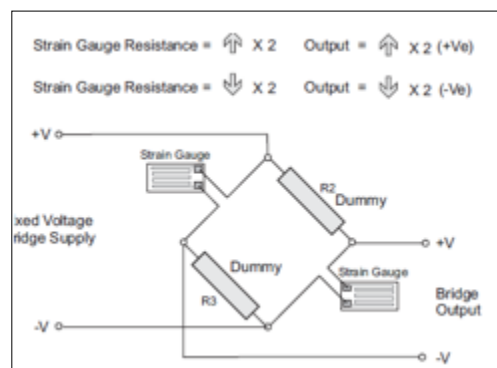


Figure 5-Half Bridge 1

1.2.3.3 Half bridge 2 (Adjacent arms)

In this case the adjacent strain gauges cancels out the strains produced which means that they would measure the same magnitude of strains but the direction of the strain would be opposite. One will measure the compressive strain while the other would measure the tensile strain. Like Half Bridge 1, this will also give the twice the output voltage. The only difference is of direction.

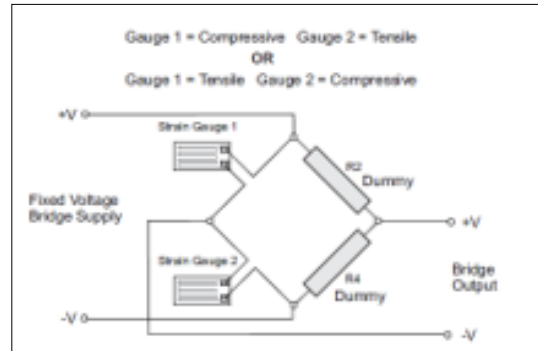


Figure 6-Half bridge 2

1.2.3.4 Full Bridge

When all the resistances are replaced by strain gauges, full bridge is formed. It gives twice the output voltage than the half bridge and hence is more sensitive than the half bridge. The two opposite strain gauges would measure the same strain and direction. For example, 1 and 4 measure tensile strain and 2 and 3 measure compressive strain. The output from the bridge is linear when all the strains are equal.

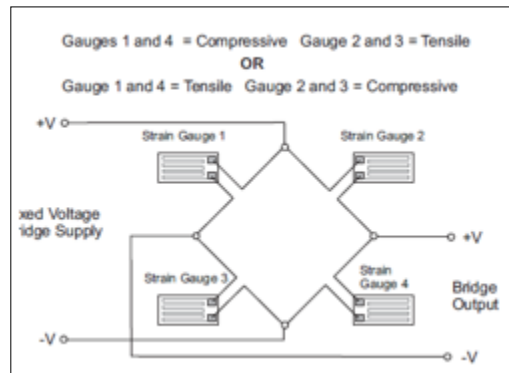


Figure 7-Full bridge

1.2.4 Strain Bridge Equation

To calculate the strain from the DC voltage following equation is used:

$$\epsilon = 4 \times \frac{V_o}{GF \times V_i \times N}$$

Where;

ϵ = Strain

V_o = Voltage measured across the bridge (V)

GF = Gauge Factor

V_i = Fixed Input Voltage applied to the bridge (V)

N = Number of active arms (gauges connected)

The output is then multiplied by 10^6 to give a result in $\mu\epsilon$ (micro strain)

1.3 Apparatus

The following figure shows experimental setup:

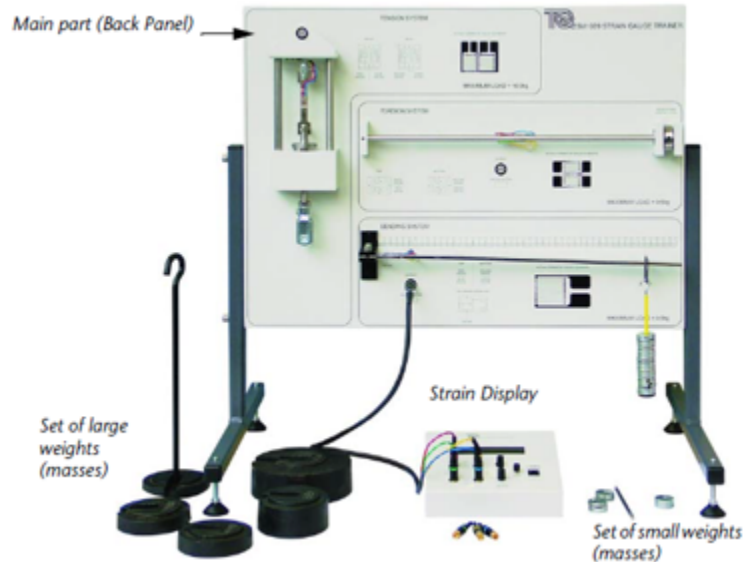


Figure 8-Lab apparatus

The apparatus contains a set of small and heavy weights. Two systems are provided which are torsion and bending system. The bending system is a solid cantilever beam which is held by secure clamps. Strain can be produced in these beams. The apparatus consists of full bridge formation which helps in measuring different strains simultaneously. A display meter shows the results as the experiment proceeds.

1.4 Experimental Safety

- Wear proper safety gear I.e., shorts and open shoes are not allowed.
- Use rubber gloves when dealing with electric circuits.
- Do not spill any liquid in the premises of the apparatus.
- In case of spill, first turn off the circuit breaker then take out the plug before cleaning the spill.

- Do not touch or operate any equipment until you are instructed to do so.
- Follow the equipment operating manual.
- Note that the equipment must be GFI protected.
- Maintain a safe distance.
- Avoid the usage of extension cords.

1.5 Experimental Procedure

- Connect the strain connection cable to the bending system.

Quarter bridge connection

- Only the red gauge should be connected to the strain display as a connection showing quarter bridge. The dummy plugs should be connected to other three sockets.
- Switch on the power supply to get the strain display. Configuration should be adjusted to 1.
- Slide the knife edge hanger onto the beam to 420 mm position carefully. Give atleast one minute to the equipment to stabilize, then press and hold the 0 button until the reading becomes '0'.
- Note down the strain reading and voltage value in the table.
- Now hook a small weight hanger to the knife edge hanger.
- The weight hanger is 10g. Add more weight to reach the total weight of 50g on to the weight hanger. Now note the voltage and strain reading.
- Keep on adding weight till you reach 500g. Note down the voltage and strain reading with each addition of 50 g.

Half bridge 1 connection – opposite arms

Repeat the above procedure with following alterations;

- Now connect the red and blue gauge to the strain display.
- Fit the dummy plugs to the sockets.
- Change the configuration to 2.

Half bridge 2 connection – adjacent arms

Keep everything the same except;

- Connect the green and red gauge to the strain display.

Full bridge connection

- Connect the red and blue gauge to the opposite sockets.
- Connect the yellow and green gauge to the opposite sockets.
- Adjust the configuration to 4.

1.6 Presentation of Raw Experimental Data

1.6.1 Quarter bridge

Table 1-Quarter bridge table

Quarter Bridge		Active arm: 1	
Load position: 420mm		Gauge factor: 2.16	
Load (g)	Strain Reading ($\mu\epsilon$)	Output (μV)	Calculated strain ($\mu\epsilon$)
0	0	0	0
50	13	36	0.552
100	27	74	1.1
150	40	110	1.71
200	55	150	2.3
250	69	188	2.9
300	83	225	3.9
350	97	263	4
400	109	296	4.5
450	123	334	5.1
500	137	371	5.7

1.6.2 Half Bridge 2 (adjacent arms)

Table 2-Half Bridge 2 table

Half Bridge 2 (Adjacent Arm)		Active arm: 2	
Load position: 420mm		Gauge factor: 2.16	
Load (g)	Strain Reading ($\mu\epsilon$)	Output (μV)	Calculated strain ($\mu\epsilon$)
0	0	0	0
50	16	89	0.7

100	31	169	1.3
150	45	245	1.9
200	59	320	2.47
250	72	392	3
300	86	465	3.6
350	100	542	4.2
400	113	613	4.7
450	127	690	5.3
500	140	755	5.8

1.6.3 Half Bridge 1 (opposite arms)

Table 3-Half Bridge 1 table

Half Bridge 1 (Opposite Arm)		Active arm: 2	
Load position: 420mm		Gauge factor: 2.16	
Load (g)	Strain Reading ($\mu\epsilon$)	Output (μv)	Calculated strain ($\mu\epsilon$)
0	0	0	0
50	16	90	0.69
100	30	162	1.2
150	43	235	1.8
200	56	306	2.4
250	69	374	2.9
300	82	447	3.4
350	95	519	4
400	109	592	4.6
450	122	664	5.1
500	136	737	5.7

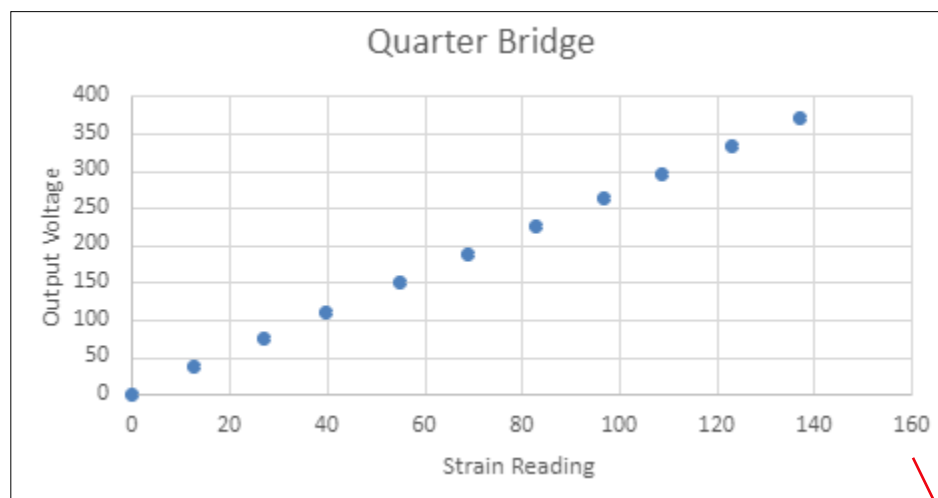
1.6.4 Full Bridge

Full Bridge	Active arm: 4
-------------	---------------

Load position: 420mm		Gauge factor: 2.16	
Load (g)	Strain Reading ($\mu\epsilon$)	Output (μV)	Calculated strain ($\mu\epsilon$)
0	0	0	0
50	17	190	0.7
100	34	367	1.4
150	45	485	1.9
200	59	778	3
250	72	778	3
300	85	925	3.6
350	99	1072	4.2
400	112	1357	5.3
450	125	1357	5.3
500	138	1500	5.8

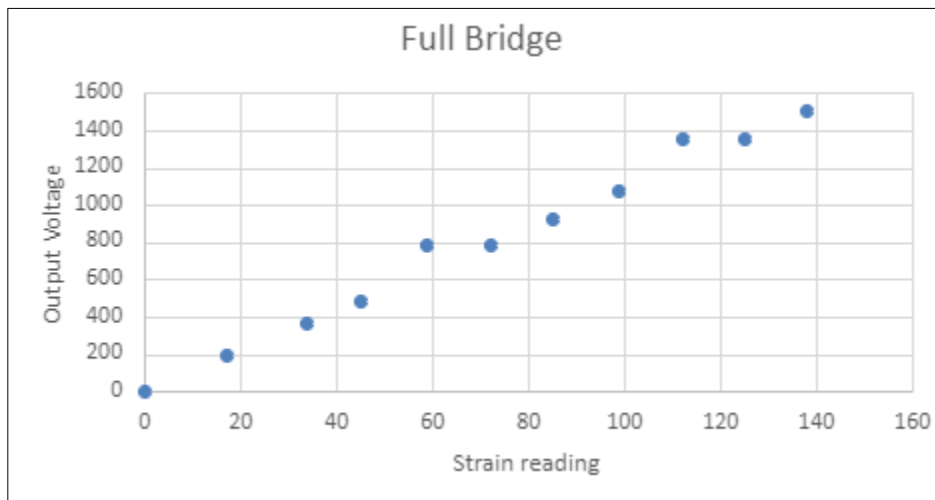
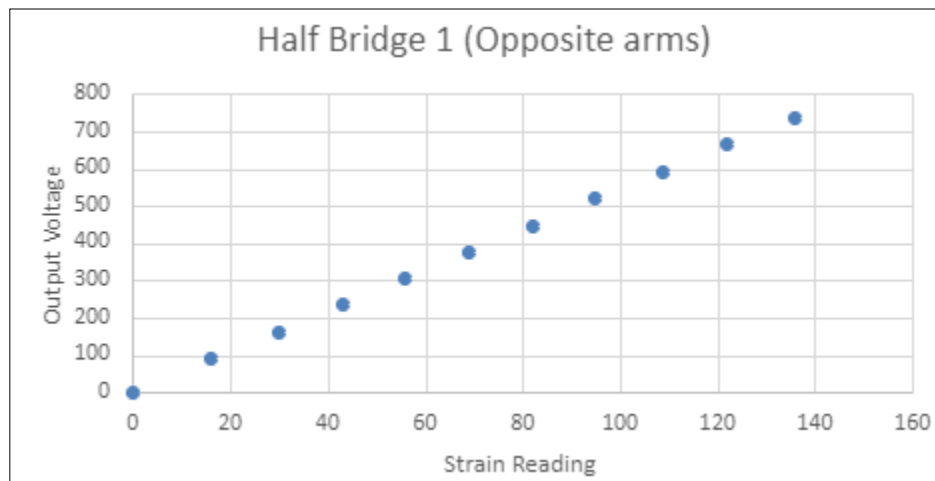
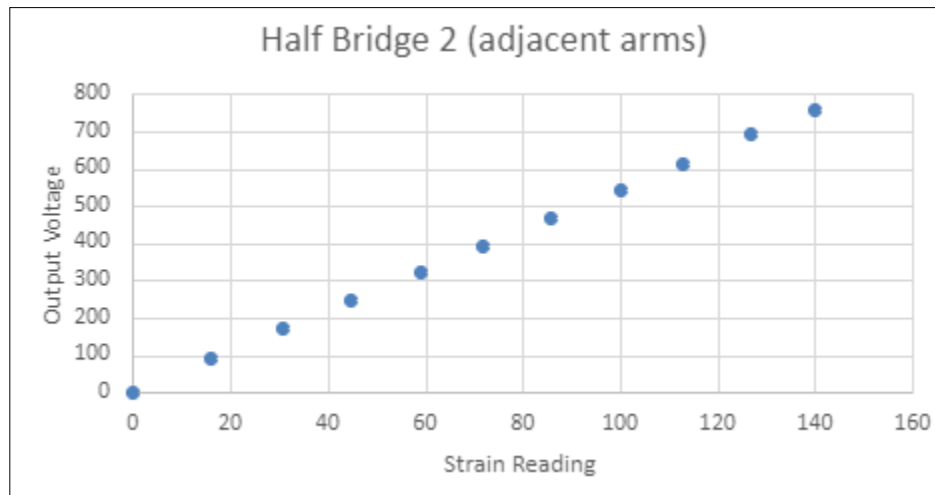
2.1 Interpretation of Experimental Data

Should use EES plot for this lab



This is excel chart.

no equation.



The above charts clearly show that as the strain goes up the output voltage goes up also. This is in accordance with the theory of the strain gauges. The only difference is that the Quarter Bridge produces less voltage as compared to the half bridges of both types. The full bridge acts in the

same way as the half bridge, the only advantage is that that it can also describe the two types of strains produced simultaneously.

Conclusion

The above experiment conducted showed the working of the strain gauges and their performance in different arrangements and scenarios. One can say that the half bridge is much affective than its counter parts as it is more sensitive and provide twice the output. But it cannot provide the clear info about the direction of strain. For that one can use full bridge configuration and can observe the strains in both directions.

Appendix

Excel sheet calculations are as follows;

Half Bridge 2 (Adjacent Arm)		Active arm: 2				Full Bridge		Active arm: 4	
Load position: 420mm		Gauge factor: 2.16				Load position: 420mm		Gauge factor: 2.16	
Load (g)	Strain Reading ($\mu\epsilon$)	Output (μV)	Calculated strain ($\mu\epsilon$)			Load (g)	Strain Reading ($\mu\epsilon$)	Output (μV)	Calculated strain ($\mu\epsilon$)
0	0	0	0			0	0	0	0
50	16	89	0.7			50	17	190	0.7
100	31	169	1.3			100	34	367	1.4
150	45	245	1.9			150	45	485	1.9
200	59	320	2.47			200	59	778	3
250	72	392	3			250	72	778	3
300	86	465	3.6			300	85	925	3.6
350	100	542	4.2			350	99	1072	4.2
400	113	613	4.7			400	112	1357	5.3
450	127	690	5.3			450	125	1357	5.3
500	140	755	5.8			500	138	1500	5.8

Quarter Bridge		Active arm: 1				Half Bridge 1 (Opposite Arm)		Active arm: 2	
Load position: 420mm		Gauge factor: 2.16				Load position: 420mm		Gauge factor: 2.16	
Load (g)	Strain Reading ($\mu\epsilon$)	Output (μV)	Calculated strain ($\mu\epsilon$)			Load (g)	Strain Reading ($\mu\epsilon$)	Output (μV)	Calculated strain ($\mu\epsilon$)
0	0	0	0			0	0	0	0
50	13	36	0.552			50	16	90	0.69
100	27	74	1.1			100	30	162	1.2
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500	137	371	5.7			500	136	737	5.7

**MEASUREMENT AND INSTRUMENTATION LABORATORY
FALL 2021**

LABORATORY REPORT # 6

TOPICS COVERED IN LABORATORY EXPERIMENT #6

**EXPERIMENT #6
SONAR SENSOR CALIBRATION**

The objectives of the experiment are to:

- 1. Understand the working principle of sonar sensor**
- 2. Collect measurement data using LabVIEW virtual instruments**
- 3. Determine the calibration equation using EES**

**MEASUREMENT AND INSTRUMENTATION LABORATORY
FALL 2021**

LABORATORY HANDOUT FOR EXPERIMENT 6

SONAR SENSOR CALIBRATION

SONAR SENSOR CALIBRATION

Objectives:

1. Understand the working principle of sonar sensor
2. Collect measurement data using LabVIEW virtual instruments
3. Determine the calibration equation using EES

Theory:

Sonar is a technique that uses sound propagation (usually underwater, as in submarine navigation) to navigate, communicate with or detect objects on or under the surface of the water. Two types of technology share the name "sonar": *passive* sonar is essentially listening for the sound made by vessels; *active* sonar is emitting pulses of sounds and listening for echoes. Active sonar sensors are also often used in mobile robotics to detect the objects in the surrounding environment. We will be using active sonar sensor in the experiment.

Active sonar sensors are fitted with an emitter that generates ultrasonic waves and a receiver that captures them after hitting a target. A timer calculates how long it takes for the signal to return and given the speed of sound in air, the distance of the remote target can be measured.

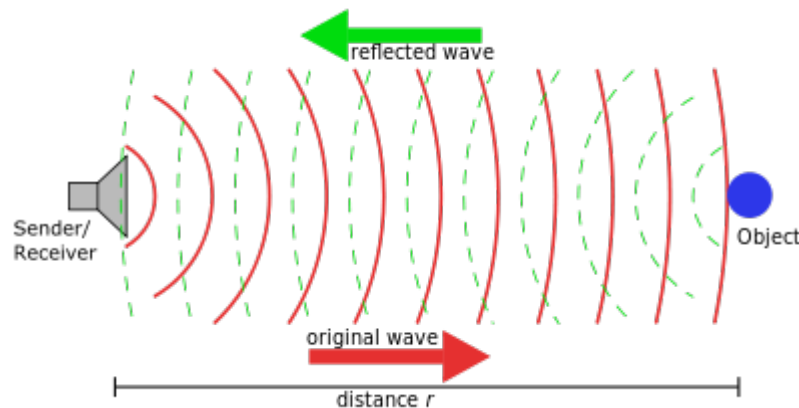


Figure 1 principle of an active sonar (from <https://en.wikipedia.org/wiki/Sonar>).

Sonar sensors are great for long-distance measurements. However, in general, these devices do not have good close-range measurements and their resolution can be relatively coarse.

Apparatus:

The sonar sensor on the mechatronic trainer is pictured in Figure 2. The voltage signal generated from the sonar sensor is proportional to the distance between the target and the sonar sensor. As the target moving away from the sonar sensor, the measured voltage increases.



Figure 2 Sonar sensor on QNET mechatronic sensors trainer.

The virtual instrument used to collect data using the sonar sensor is shown in Figure 3. The virtual instrument used to calibrate sonar range data is shown in Figure 4.

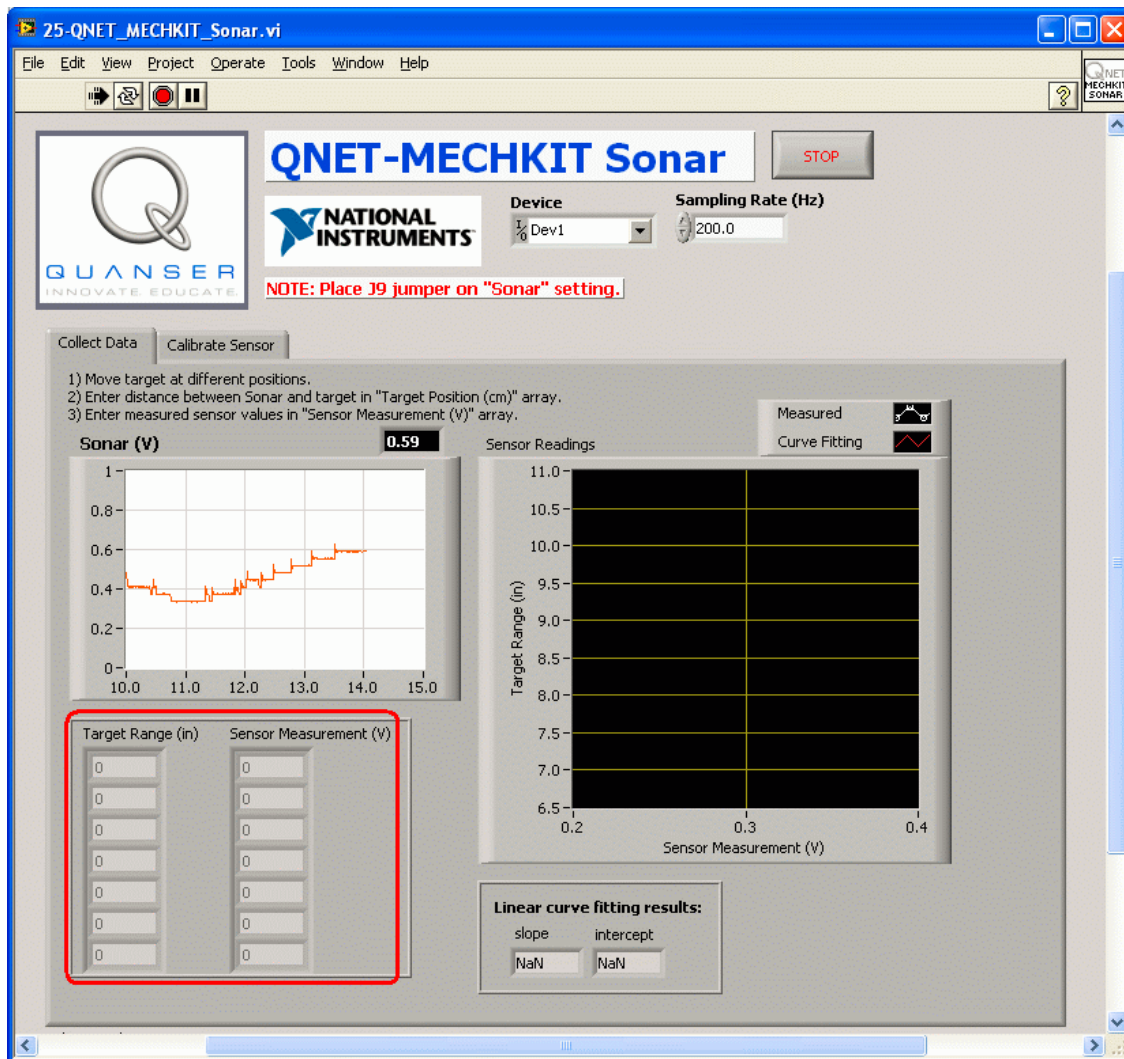


Figure 3 Collecting sonar data.

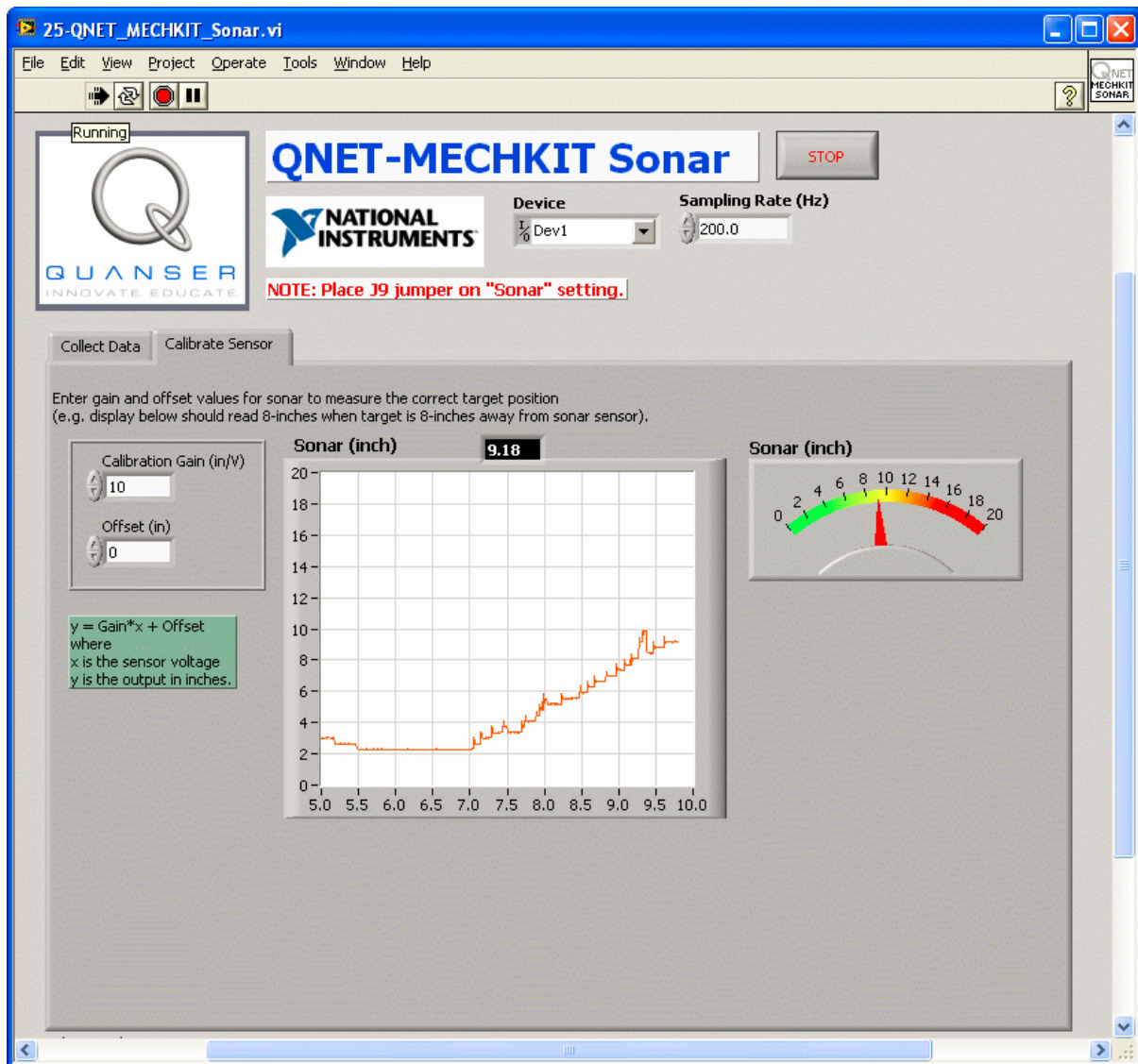


Figure 4 Calibrating the sonar sensor.

Procedures:

1. **Ensure J9 is set to Sonar.**
2. Open the QNET_MECHKIT_Sonar.vi. **Make sure the correct Device is chosen.**
3. Run QNET_MECHKIT_Sonar.vi.
4. To **collect data**, get a target, such as a sturdy piece of cardboard that is at least 10cm x 10cm with a reflective colour like white or yellow.
5. Begin with the target close to the sonar sensor and slowly move it upward.
6. Once the lower end of its range of operation is found, enter the distance between the target and the sonar sensor in the Target Range (in) array, as shown in Figure 3.
7. Enter the corresponding measured voltage from the sonar sensor in the Sensor Measurement (V) array, as shown in Figure 3.

8. Repeat for different target positions. Table 1 can be filled up. The sonar sensor is linear and the slope and intercept are generated and the fitted curve is automatically plotted.

Table 1 Collected data for sonar sensor calibration.

Target Range (in)	Sensor Measurement (V)

9. To calibrate sensor, select the **Calibrate Sensor** tab and enter Gain (in cm/V) and Offset (in cm) coefficients which are obtained from the previous steps. Make sure the coefficients are correct. When the target is 10.0 inches away, do the Sonar (inch) displays also show 10.0 inches? What is the difference between the actual position of the target and the displayed position calibrated by the sonar sensor? Change the target position at least 5 times to fill up Table 2.

Table 2 Comparison between the actual position of the target and the calculated position of the target.

Actual Target Position T (in)	Calculated Target Position T' (in)	Difference (T-T')

10. Click on Stop button to stop the VI.

Laboratory Report:

1. Create a parametric table in EES with the variables T (target range in inches) and V (sensor measurement in voltage).
2. Transfer the raw data into the EES table you have created.
3. Plot T (vertical axis) versus V (horizontal axis).
4. Use EES to fit the **first order polynomial** through the points.
5. Plot the equation of the curve fitting result on the plot.
6. In the Calibration Sensor tab, take note of the difference between the actual distance of the target and the calibrated/displayed distance from the sonar sensor. Discuss your discoveries.

7. Present the information in a well written standard laboratory report following the detailed report format provided to you and discussed in class.
8. Completely discuss and interpret your results including all graphs and computed results as required.

ABOVE AVERAGE

**MECHANICAL ENGINEERING DEPARTMENT
PRAIRIE VIEW A&M UNIVERSITY**



MCEG 3101 MEASUREMENT LABORATORY

Fall 2021 Section P01

LABORATORY REPORT ON

"Sonar Sensor Calibration"

**Conducted on
November 16 , 2021**

**Submitted by
Anette Lira
On
December 10, 2021**

**To
Dr. Mingli Han
*Measurement Laboratory Instructor***

MECHANICAL ENGINEERING DEPARTMENT

**MEASUREMENT LABORATORY GRADING SHEET
FALL 2021 SECTION P01**

Title of Experiment: Local Gravitational Acceleration Determination by a Simple Pendulum.

Name: Anette Lira

Date Lab was Performed: 11/16/2021 Report Due Date: 12/10/2021

<i>Ability to Conduct Experiments</i>	MAX	Your Score	Comments
Ability to demonstrate general lab safety (by your conduct and observations).	3	3	
Ability to follow the procedure and properly rephrasing the procedure to reflect what you did during the experiment.	7	7	
Ability to demonstrate knowledge of how equipment function, their limitations, and the uncertainty associated with reading the instruments.	5	5	
Ability to collect and record the raw data using appropriate units of measurement and identify the dependent and independent variables in the experiment.	5	5	
Total for Ability to Conduct Experiments	20		
Percentage for this Performance Criteria			
<i>Ability to Analyze and Interpret experimental Data in a Formal Report</i>			
Report format (Ability to properly format and present a technical report)	13	13	
Provides appropriate abstracts for the experimental report	5	4	
Ability to analyze the data using appropriate software to generate the required parameters using consistent units	27	27	
Ability to present the data (raw /derived) in tabular and graphical form to meet the objectives and to aid in interpretation.	14	13	
Ability to discuss the raw and derived data/graphs and assess the validity of the results in relation to the underlying theory and expected trends.	14	14	
Ability to draw appropriate and reasonable conclusions in relations to each of the experimental objectives. One conclusion statement for each objective.	7	7	
Total for Ability to Analyze and Interpret experimental Data	80		
TOTAL FOR THIS LAB		98	

Anette Lira
Mechanical Engineering Student
2763 Picasso Lane
Brownsville Tx 78520
Cell: 956-295-0756
E-mail: alira@pvamu.edu

Dr. Mingli Han
Measurement Laboratory Instructor
Prairie View A&M University
S. R. Collins Engineering Technology Building Room 311

Dear Dr. Han:

October 19, 2021

The following pages are a detailed report for lab 5 of MCEG 3101 Measurement Laboratory, "Sonar Sensor Calibration". This report addresses the working principle of sonar sensor. We will also use the engineering equation solver to obtain statistical analysis of the experimental data. The lab was performed on November 9, 2021 and was submitted on December 5, 2021.

If you have any questions or concerns, please call, or email me at any time.

Sincerely,

Anette Lira
Enclosure: Lab Report

Abstract

The purpose of this experiment is to use statistical analysis data using the sum, mean, deviation, the mean deviation and standard deviation through the Engineering Equation Solver program. The apparatus that was used in this lab to is a sonar sensor calibration on a mechatronic trainer. In the experiment we had the sonar sensor, along the side we have a ruler and a piece of paper to cover the sounds in which we want to measure. This would help obtain accurate measurement of the range in which every time we have a larger size between the sensor and the paper the numbers on the Mechkit sonar would increase. Each group got their own data and combined we obtain the experimental data that was given by Dr. Han. By completing the experiment, we determine the results, and they show the importance of measurement. In every length, at least one student had a different number compared to other measure from other student. The target Range measurement would show that there was an increase on the sonar measurement with the data collected as well as the actual position of the paper and the sonar calibration The major conclusion that we can see is that from the results we calculated are depicted by the data that was obtained and analyzed.

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CHAPTER 1

SONAR SENSOR CALIBRATION

1.1 Objectives:

1. Understand the working principle of sonar sensor
2. Collect measurement data using LabVIEW virtual instruments
3. Determine the calibration equation using EES

1.2 Theory:

Sonar is a technique that uses sound propagation (usually underwater, as in [submarine navigation](#)) to navigate, communicate with or detect objects on or under the surface of the water. Two types of technology share the name "sonar": *passive* sonar is essentially listening for the sound made by vessels; *active* sonar is emitting pulses of sounds and listening for echoes. Active sonar sensors are also often used in mobile robotics to detect the objects in the surrounding environment. We will be using active sonar sensor in the experiment.

Active sonar sensors are fitted with an emitter that generates ultrasonic waves and a receiver that captures them after hitting a target. A timer calculates how long it takes for the signal to return and given the speed of sound in air, the distance of the remote target can be measured.

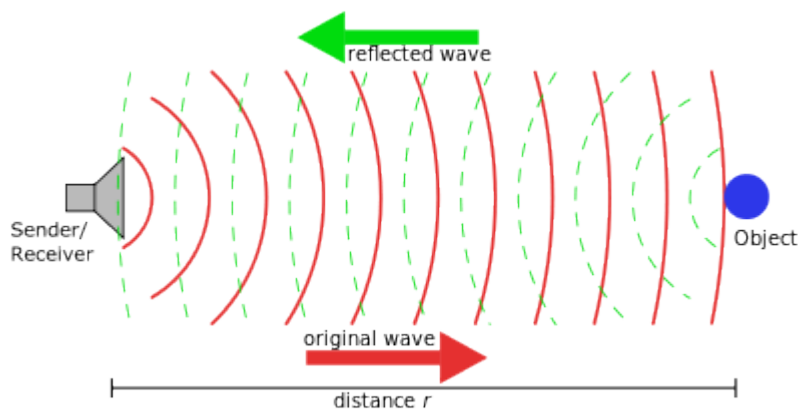


Figure 1.1 principle of an active sonar (from <https://en.wikipedia.org/wiki/Sonar>).

Sonar sensors are great for long-distance measurements. However, in general, these devices do not have good close-range measurements and their resolution can be relatively coarse.

1.3 Apparatus:

The sonar sensor on the mechatronic trainer is pictured in Figure 2. The voltage signal generated from the sonar sensor is proportional to the distance between the target and the sonar sensor. As the target moving away from the sonar sensor, the measured voltage increases.

1.4 Experimental Safety: Read and follow instructions , lab equipment would be under supervision, proper clothing and not eating in the lab.



Figure 1.2 Sonar sensor on QNET mechatronic sensors trainer.

The virtual instrument used to collect data using the sonar sensor is shown in Figure 3. The virtual instrument used to calibrate sonar range data is shown in Figure 4.

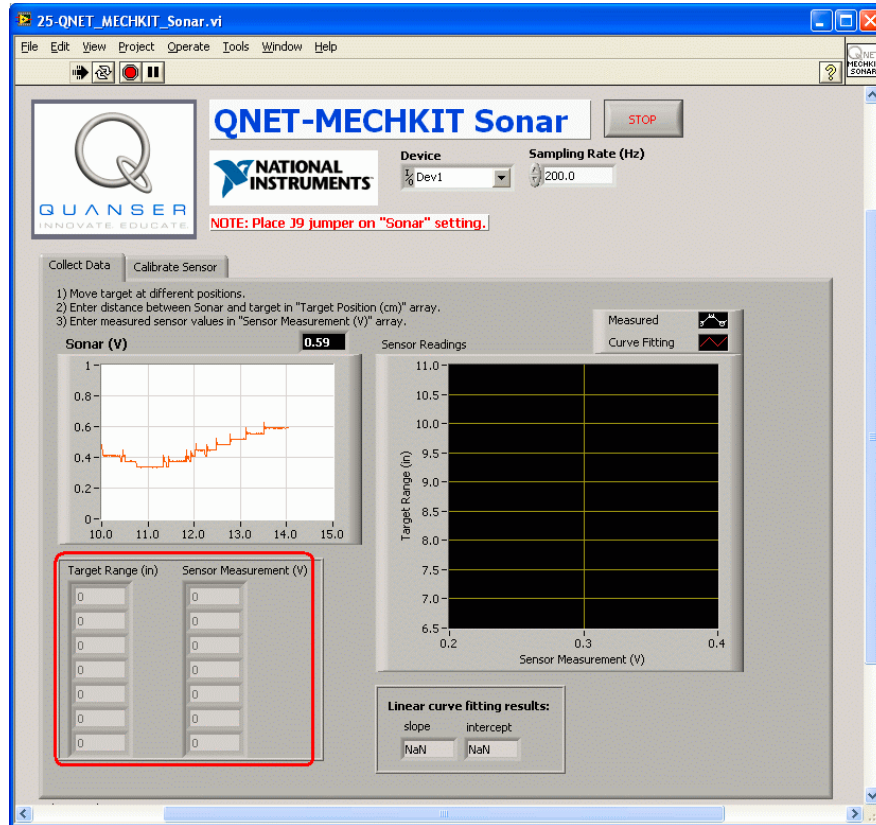


Figure 1.3 Collecting sonar data.

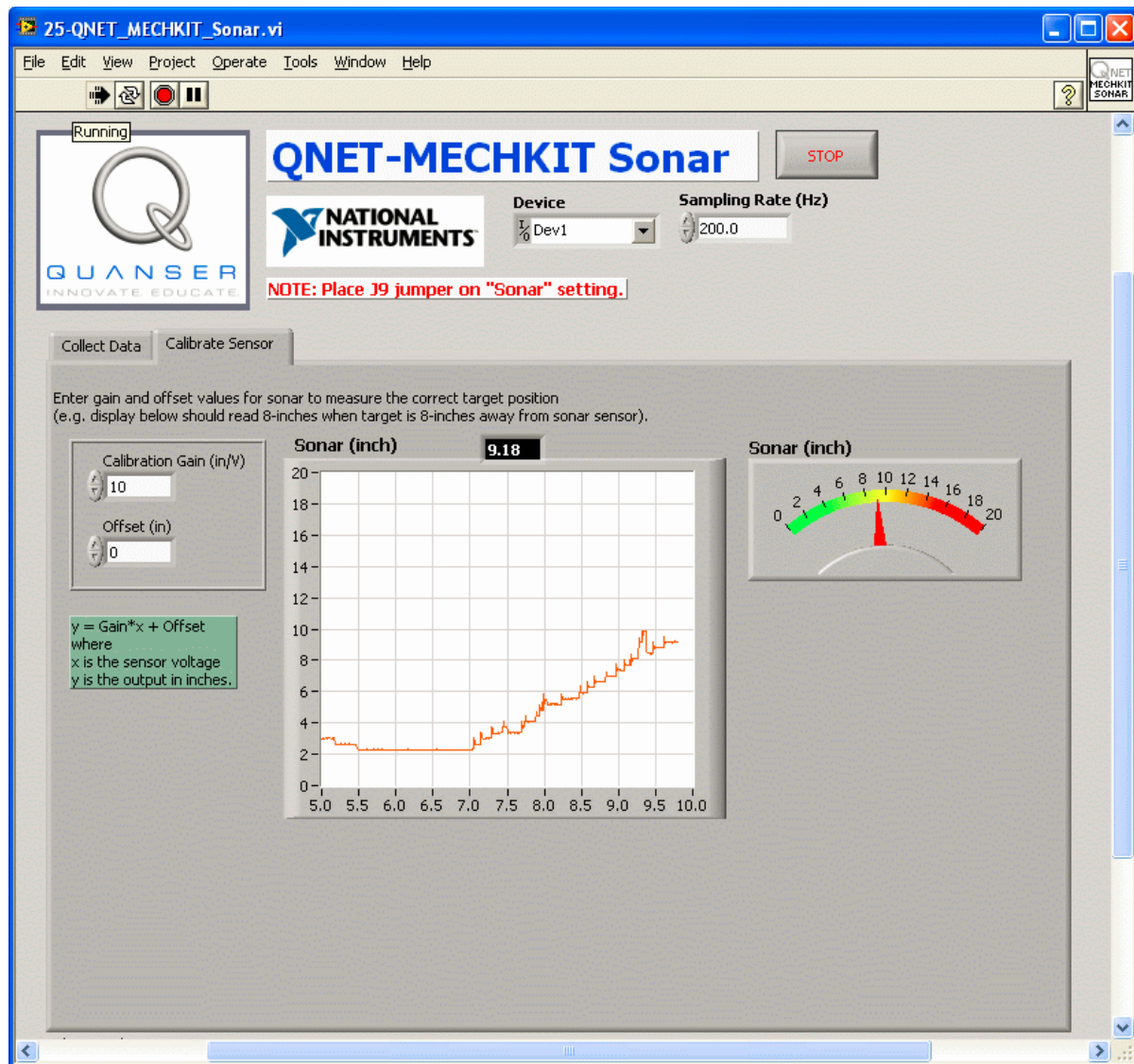


Figure 1.4 Calibrating the sonar sensor.

1.5 Procedures:

1. **Ensure J9 is set to Sonar.**
2. Open the QNET_MECHKIT_Sonar.vi. **Make sure the correct Device is chosen.**
3. Run QNET_MECHKIT_Sonar.vi.
4. To **collect data**, get a target, such as a sturdy piece of cardboard that is at least 10cm x 10cm with a reflective colour like white or yellow.
5. Begin with the target close to the sonar sensor and slowly move it upward.
6. Once the lower end of its range of operation is found, enter the distance between the target and the sonar sensor in the Target Range (inch) array, as shown in Figure 3.
7. Enter the corresponding measured voltage from the sonar sensor in the Sensor Measurement (V) array, as shown in Figure 3.
8. Repeat for different target positions. Table 1 can be filled up. The sonar sensor is linear and the slope and intercept are generated and the fitted curve is automatically plotted.

CHAPTER 2

ABILITY TO ANALYZE EXPERIMENTAL DATA

2.1 Presentation of Raw Data

Table 2.1 Collected data for sonar sensor calibration.

 1..1	1 T	2 V
Run 1	9	0.31
Run 2	11	0.38
Run 3	12	0.42
Run 4	13.5	0.45
Run 5	16	0.52
Run 6	18	0.6
Run 7	21	0.67

2.2 Presentation of Tables of derived results

9. To calibrate sensor, select the **Calibrate Sensor** tab and enter Gain (in cm/V) and Offset (in cm) coefficients which are obtained from the previous steps. Make sure the coefficients are correct. When the target is 10.0 inches away, do the Sonar (inch) displays also show 10.0 inches? What is the difference between the actual position of the target and the displayed position calibrated by the sonar sensor? Change the target position at least 5 times to fill up Table 2.

Table 2.2 Comparison between the actual position of the target and the calculated position of the target.

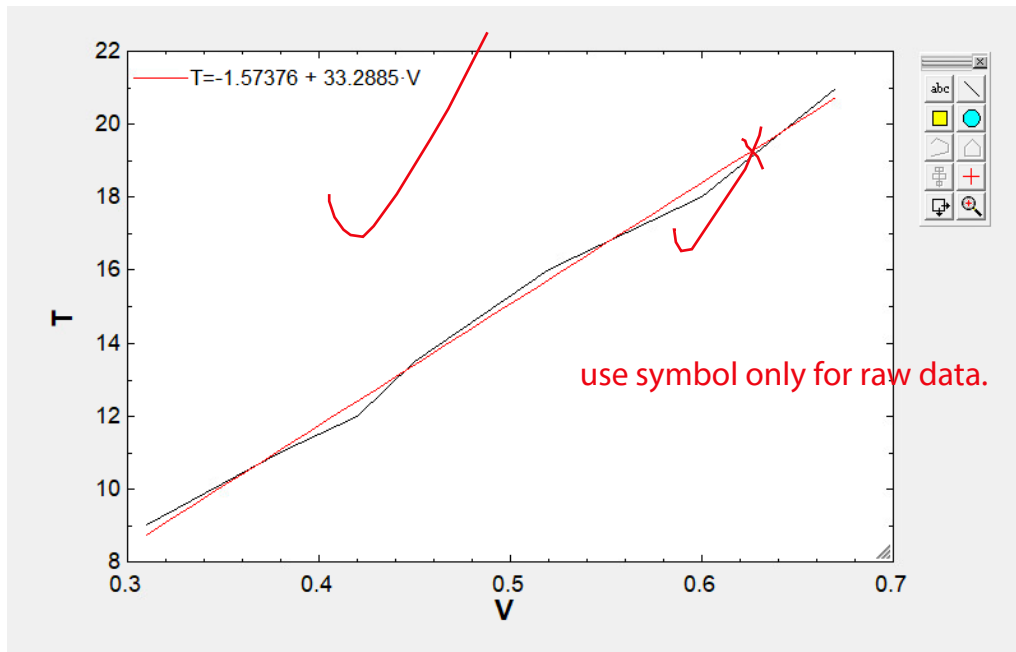
 1..5	1 T	2 T2	3 subtract
Run 1	10	6.2	3.8
Run 2	11	9.7	1.3
Run 3	15	13.43	1.57
Run 4	17.5	16.36	1.14
Run 5	20.63	17.86	2.77

Discussion: In this table we have the derived results of the EES program with the coding equations.

CHAPTER 3

ABILITY TO INTERPRET EXPERIMENTAL DATA

3.1 Presentation of Graphs/Figures and Interpretation of Results Presented by each Graph/Figure



Graph 3.1 Target Position vs Sensor

Discussion: In this graph shows that we have a positive slope of the target range and the sensor sonar that was displayed during the experiment. The y-axis of the graph measures the target range. The x-axis measures the sensor measurement. We can see that the correlation between both variables have also a positive relation. The further away the object is from the sensor the higher the voltage would have.

3.2 Conclusions based on each Objective and Results

Using the Engineering Equation Solver, we were able to conduct statistical analysis to solve different types of equations to determine the difference between the actual position and the displayed position by the calibrated sensor. The primary difference between the actual position of the target and the displayed position calibrated by the sonar sensor has a major difference between each other. For example, for Run 1 the difference would be about 3.8, on the other hand for Run 2 ,1.3 would be the difference. We can tell that having a close difference form the actual and the calculated means that the sonar has being calibrated and is running smoothly and that it is going to work as accurate as possible. The actual position is the position that we measure with the ruler from the sensor and the paper. The calculated position would be the position that the sonar is calculating throughout the calibrator. We can also tell that the further you move the object away from the sensor the higher the voltage goes.

3.2 Recommendations

I learned to use the program EES which easily gave us the solved tables using the right pattern of coding. It also shown the accuracy that the program is and can give us wide information analytical towards different aspects of the experiment. The use of EES on this lab gave us an easy way to analyze the difference between the actual position and the displayed position calibrated with the senso

Recommendations- I learned to use the program EES which easily gave us the solved tables using the right pattern of coding. It also shown the accuracy that the program is and can give us wide information analytical towards different aspects of the experiment.

AVERAGE

**MECHANICAL ENGINEERING DEPARTMENT
PRAIRIE VIEW A&M UNIVERSITY**



MCEG 3101 MEASUREMENT LABORATORY

Fall 2021 Section P01

LABORATORY REPORT ON

“SONAR SENSOR CALIBRATION”

Conducted on

August 24, 2021

Submitted by

Christopher Nweke

On

December 7, 2021

To

Dr. Mingli Han

Measurement Laboratory Instructor

**MECHANICAL ENGINEERING DEPARTMENT
MEASUREMENT LABORATORY GRADING SHEET
FALL 2021 SECTION P01**

Title of Experiment: _____

Name: _____

Date Lab was Performed: _____ **Report Due Date:** _____

<i>Ability to Conduct Experiments</i>	MAX	Your Score	Comments
Ability to demonstrate general lab safety (by your conduct and observations).	3	3	
Ability to follow the procedure and properly rephrasing the procedure to reflect what you did during the experiment.	7	7	
Ability to demonstrate knowledge of how equipment function, their limitations, and the uncertainty associated with reading the instruments.	5	5	
Ability to collect and record the raw data using appropriate units of measurement and identify the dependent and independent variables in the experiment.	5	5	
Total for Ability to Conduct Experiments	20		
Percentage for this Performance Criteria			
<i>Ability to Analyze and Interpret experimental Data in a Formal Report</i>			
Report format (Ability to properly format and present a technical report)	13	10	
Provides appropriate abstracts for the experimental report	5	4	
Ability to analyze the data using appropriate software to generate the required parameters using consistent units	27	27	
Ability to present the data (raw /derived) in tabular and graphical form to meet the objectives and to aid in interpretation.	14	10	
Ability to discuss the raw and derived data/graphs and assess the validity of the results in relation to the underlying theory and expected trends.	14	12	
Ability to draw appropriate and reasonable conclusions in relations to each of the experimental objectives. One conclusion statement for each objective.	7	7	
Total for Ability to Analyze and Interpret experimental Data	80		
TOTAL FOR THIS LAB		90	

Letter of Transmittal

Christopher Nweke
Mechanical Engineering Student
8505 Barron Wood Circle East
Cell:7134174629
Cnweke1@pvamu.edu

Dr. Mingli Han
Measurements Laboratory
Prairie View A&M
S.R Collins Engineering Technology Building
Room 311

Dear Dr. Han

The following pages are a detailed report for lab 6 of MCEG Measurement and Instrumentation Laboratory, “Sonar Sensor Calibration Lab”. This report addresses the use of a sonar sensor used to collect data using sonar sensors. A virtual instrument is used to calibrate sonar range in this lab. In this lab we will utilize EES to determine the calibration and organize and plot sonar data and equation using a curve fit, tables and code. The lab is due December 10th, 2021, if you have any questions or concerns, please call or email me at any time.

Sincerely,
Christopher Nweke

Abstract

The purpose of this lab experiment was to learn how to utilize EES in order to solve an engineering problem. The purpose of this experiment is to understand and analyze Calibration of sonar sensors shown in this lab. We will utilize coding programs within EES to find critical values such as differences between actual target position variables and calculate target position. Also to organize the data given from sonar data and make analysis based on the information.

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Chapter 1 Ability to Conduct Experiments

1.1 Objective:

Understand the working principle of sonar sensors.

Collect measurement data using LabVIEW virtual instruments, and

Determine the calibration equation using EES.

1.2 Theory:

Sonar is a technique that uses sound propagation (usually underwater, as in submarine navigation) to navigate, communicate with or detect objects on or under the surface of the water. Two types of technology share the name “sonar”: passive sonar is essentially listening for the sound made by Vessels; active sonar is emitting pulses of sounds and listening for echoes. Active sonar sensors are also often used in mobile robotics to detect the objects in the surrounding environment. We will be using active sonar sensor in the experiment. Active sonar sensors are fitted with an emitter that generates ultrasonic waves and a receiver that captures them after hitting a target. A timer calculates how long it takes for the signal to return and given the speed of sound in air, the distance of the remote target can be measured.

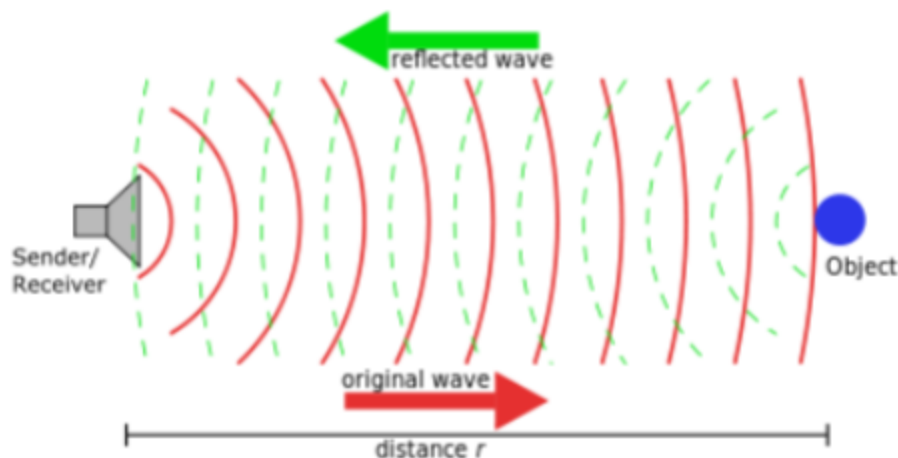


Figure 1 principle of an active sonar (from <https://en.wikipedia.org/wiki/Sonar>).

Sonar sensors are great for long-distance measurements. However, in general, these devices do not have good close-range measurements and their resolution can be relatively coarse.

1.3 Apparatus:

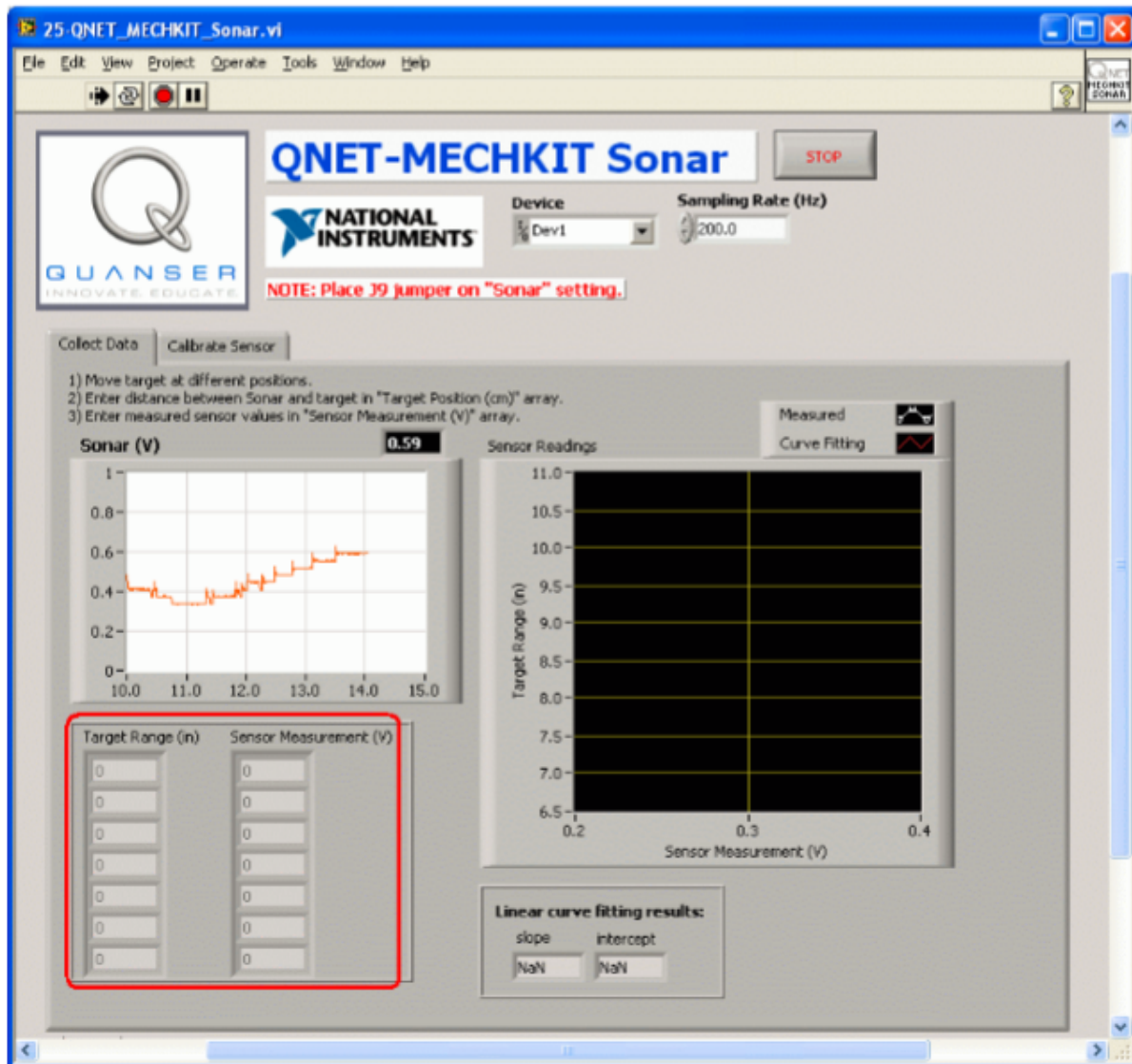
The sonar sensor on the mechatronic trainer is pictured in Figure 2.

The voltage signal generated from the sonar sensor is proportional to the distance between the target and the sonar sensor. As the target moves away from the sonar sensor, the measured voltage increases.



Figure 2 Sonar sensor on QNET mechatronic sensors trainer.

The virtual instrument used to collect data using the sonar sensor is shown
virtual instrument used to calibrate sonar range data is shown in Figure 4.



1.4 Experimental Safety:

The safety measure that we need to be familiar with for this lab are:

1. Read the Lab Manual carefully before starting the experiment. Use the proper tool for the job.
- 2) Always wear the proper PPE for the work task.
- 3) Make sure chemicals are properly labeled and stored

- 4) Communicate hazards to other personnel.
- 5) Stop work when needed to address hazards.

1.5 Procedures:

1. Ensure J9 is set to Sonar.
2. Open the QNET_MECHKIT_Sonar.vi.
Make sure the correct Device is chosen.
3. Run QNET_MECHKIT_Sonar.vi.
4. To collect data, get a target, such as a sturdy piece of cardboard that is at least 10 Cm x 10cm with a reflective colour like white or yellow.
5. Begin with the target close to the sonar sensor and slowly move it upward.
6. Once the lower end of its range of operation is found, enter the distance between the target and the sonar sensor in the Target Range (inch) array, as shown in Figure 3.
7. Enter the corresponding measured voltage from the sonar sensor in the Sensor Measurement (V) array, as shown in Figure 3.
8. Repeat for different target positions. Table 1 can be filled up. The sonar sensor is linear and the slope and intercept are generated, and the fitted curve is automatically plotted.

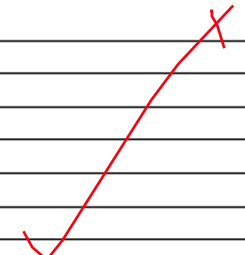
1.6 Raw Data

Below is the given data from the experiment. These values will be utilized in EES to compute critical data T1 and T2 represent actual target position and calculated target. In total there are two separate tables.

missing table captions

Target Range (inch)	Sensor measurement (V)
9	0.31
11	.38
12	.42
13.5	.45
16	.52
18	.6
21	.67

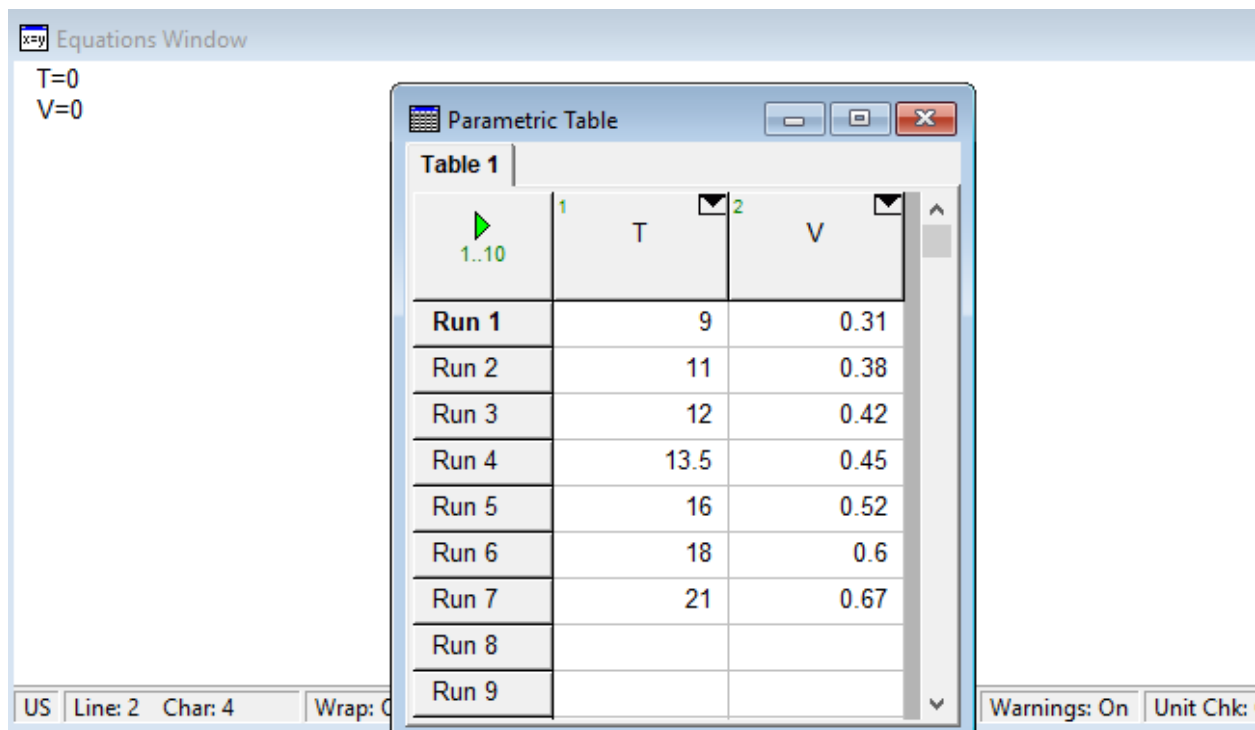
Actual Position (inch)	Calculated Position (inch)
10	6.2
11	9.7
15	13.43
17.5	16.36
20.63	17.86



Chapter 2

2.1 Detailed computer analysis

Table 2.1



The screenshot shows the EES software interface. The 'Equations Window' is open, displaying the equations $T=0$ and $V=0$. A 'Parametric Table' window is also open, showing 'Table 1'. The table has three columns: a 'Run' column, a 'T' column, and a 'V' column. The data is as follows:

Run	T	V
Run 1	9	0.31
Run 2	11	0.38
Run 3	12	0.42
Run 4	13.5	0.45
Run 5	16	0.52
Run 6	18	0.6
Run 7	21	0.67
Run 8		
Run 9		

Above is data given from sonar sensor calibration. T in this table represents the target range in inches as well as V sensor measurement. We set the variables in EES as well as runs.

2.2 Presentation of Derived results

Table 1

In the tables below are derived results derived from the tables from 2.1 as well as table two. The data on the tables demonstrates actual target position and calculated target position. The purpose of this table is to compare both variables as well as find the difference between both variables. We will also utilize EES code to understand the difference between data.

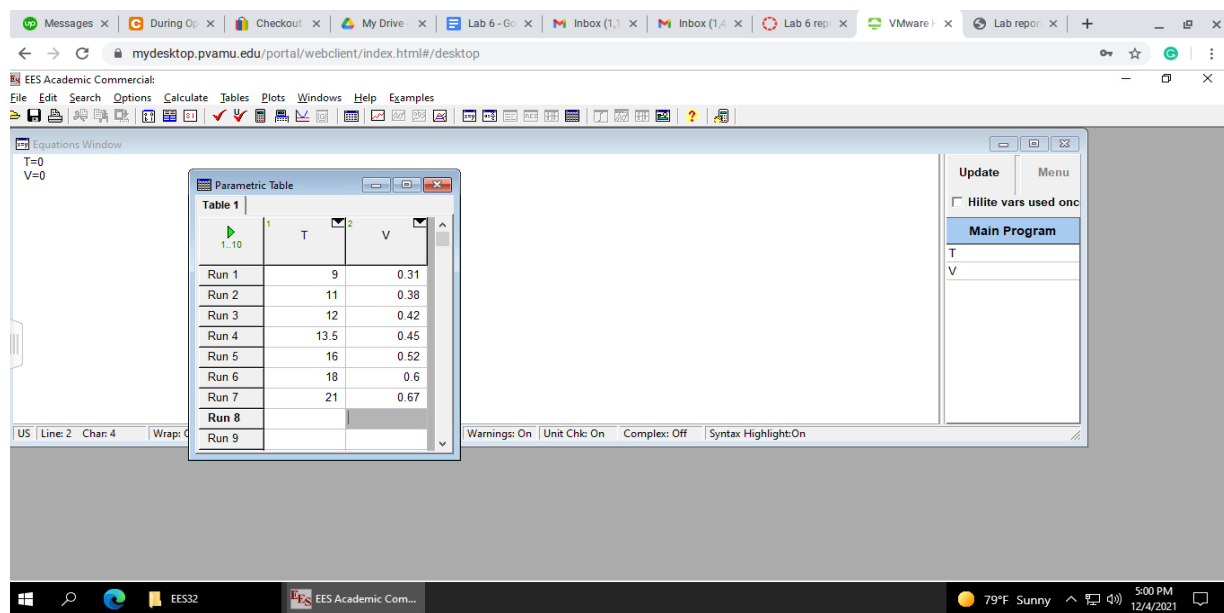


Figure 2.1

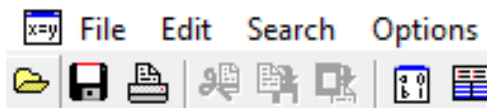
Table 2.2

1..10	T1	T2	T
Run 1	10	6.2	3.8
Run 2	11	9.7	1.3
Run 3	15	13.43	1.57
Run 4	17.5	16.36	1.14
Run 5	20.63	17.86	2.77
Run 6			
Run 7			
Run 8			
Run 9			
Run 10			

```

x=y Equations Window
{T1=0
T2=0}
Subtract=T1-T2

```

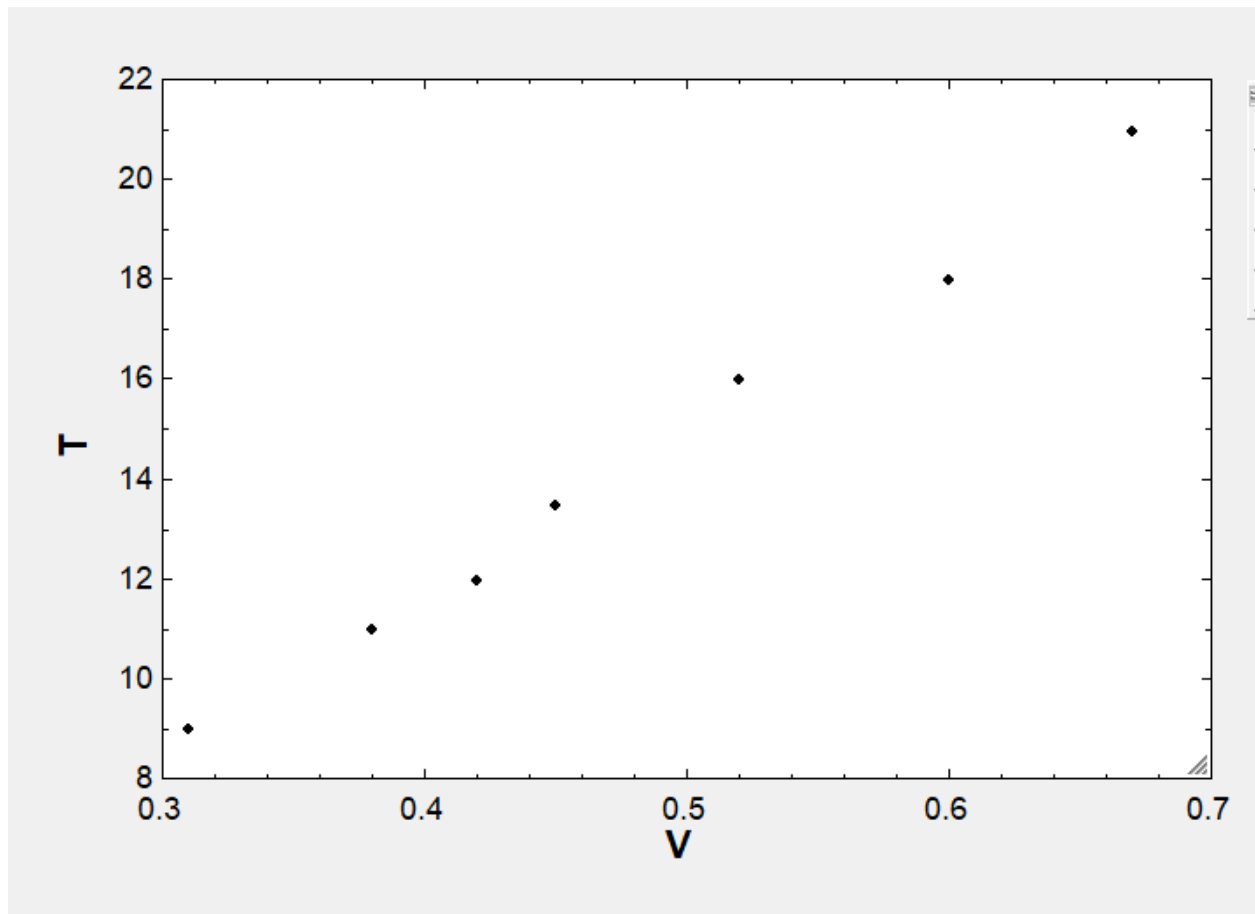


T1=0
 V=0
 T2=0
 Subtract=T2-T1

Above data gives the data and coding of our values given. Comment is an important feature for the EES computer system in order to get calculations for data.

3.1 Presentation of Graphs/figures and interpretation of results by graph

Table 3.1



Based on the plots and points we can conclude that there is a correlation between our T and V values. We can make an assumption that V or sensor measurements in respect to target range have direct correlation. As the sensor measurements increase we see a trend that target range increases.

Table 2.2

 1..10	¹ T1	² T2	³ T
Run 1	10	6.2	3.8
Run 2	11	9.7	1.3
Run 3	15	13.43	1.57
Run 4	17.5	16.36	1.14
Run 5	20.63	17.86	2.77
Run 6			
Run 7			
Run 8			
Run 9			
Run 10			

In this table we calculated the difference between actual position and the calculated position on the graph.

In this figure we utilize the curve fit on the graph below in EES in order to analyze observed T function and understand critical data from this algebraic expression.

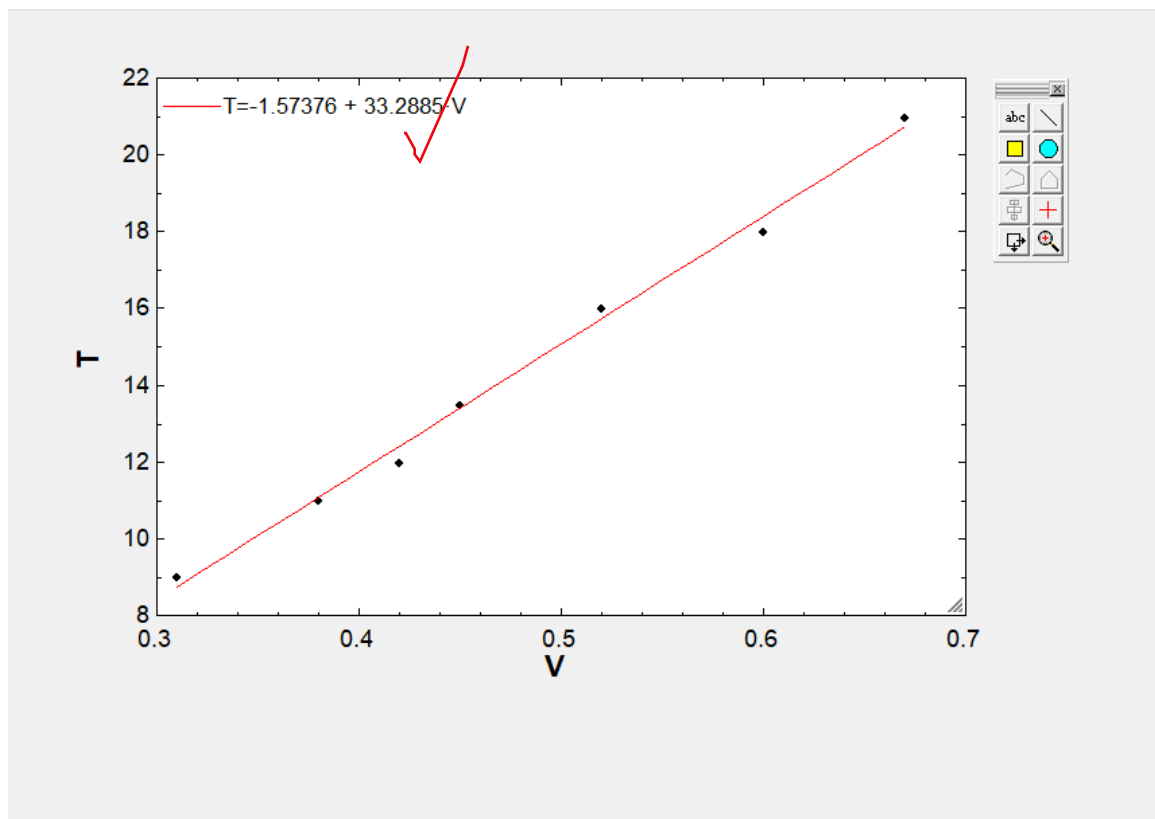


Figure 3.1

3.2 Conclusion based on each objective and results

In conclusion, this lab has taught how to apply EES to real world engineering problems. We learned how to think critically on data provided in the lab from sonar sensors as well as get in depth experience in engineering application software. In this lab we analyzed and solved major

lab objectives such as understanding the working principle of sonar sensors. Collect measurement data using LabVIEW virtual instruments, and Determine the calibration equation using EES.

3.3 Recommendations:

I have learned how to compute values in EES as well as how to use EES. Prior to this lab I have experimented with software but software is much simpler than other software's that are much more intensive.

BELOW AVERAGE

**MECHANICAL ENGINEERING DEPARTMENT
PRAIRIE VIEW A&M UNIVERSITY**



MCEG 3101 MEASUREMENT LABORATORY

Fall 2021 Section P01

LABORATORY REPORT ON

Sonar sensor calibration

**Conducted on
November 16, 2021**

Submitted by

**On
November 1st, 2021**

To

**Dr. Mingli Han
*Measurement Laboratory Instructor***

**MECHANICAL ENGINEERING DEPARTMENT
MEASUREMENT LABORATORY GRADING SHEET
FALL 2021 SECTION P01**

Title of Experiment: _____

Name: _____

Date Lab was Performed: _____ **Report Due Date:** _____

<i>Ability to Conduct Experiments</i>	MAX	Your Score	Comments
Ability to demonstrate general lab safety (by your conduct and observations).	3	3	
Ability to follow the procedure and properly rephrasing the procedure to reflect what you did during the experiment.	7	7	
Ability to demonstrate knowledge of how equipment function, their limitations, and the uncertainty associated with reading the instruments.	5	5	
Ability to collect and record the raw data using appropriate units of measurement and identify the dependent and independent variables in the experiment.	5	5	
Total for Ability to Conduct Experiments	20		
Percentage for this Performance Criteria			
<i>Ability to Analyze and Interpret experimental Data in a Formal Report</i>			
Report format (Ability to properly format and present a technical report)	13	7	
Provides appropriate abstracts for the experimental report	5	4	
Ability to analyze the data using appropriate software to generate the required parameters using consistent units	27	5	
Ability to present the data (raw /derived) in tabular and graphical form to meet the objectives and to aid in interpretation.	14	12	
Ability to discuss the raw and derived data/graphs and assess the validity of the results in relation to the underlying theory and expected trends.	14	14	
Ability to draw appropriate and reasonable conclusions in relations to each of the experimental objectives. One conclusion statement for each objective.	7	4	
Total for Ability to Analyze and Interpret experimental Data	80		
TOTAL FOR THIS LAB		66	

ABSTRACT:

Sonar sensors work by sending out a sound wave at a frequency above the range of human hearing. By calculating the travel time and the speed of sound, the distance can be calculated. They are specially used to detect the presence of objects below the surface of water. A cross talk signal is transmitted from a first ultrasonic sensor to a second one. The amplitude of cross talk signal is compared with stored value and the sensitivity is measured as a function of comparison.

[start a new page](#)

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[Start a new page](#)

Chapter 1 Ability to Conduct Experiments

1. Objectives:

Following are the objectives of this experiment:

1. Understand the working principle of sonar sensor
2. Collect measurement data using LabVIEW virtual instruments
3. Determine the calibration equation using EES

2. Theory:

Sonar is a technique that uses sound propagation (normally underwater), to navigate, communicate with or detect objects on or under the surface of water. It can either be passive or active. *Passive* sonar is essentially listening for the sound made by vessels, while the latter is emitting pulses of sounds and listening for echoes. Active sonar sensors are also often used in mobile robotics to detect the objects in the surrounding environment. We will be using active sonar sensor in the experiment.

Active sonar sensors are fitted with an emitter that produces ultrasonic waves and a receiver which captures them after hitting a target. A timer calculates how long it takes for the signal to return and since the speed of sound in air is known, the distance of the remote target can be measured.

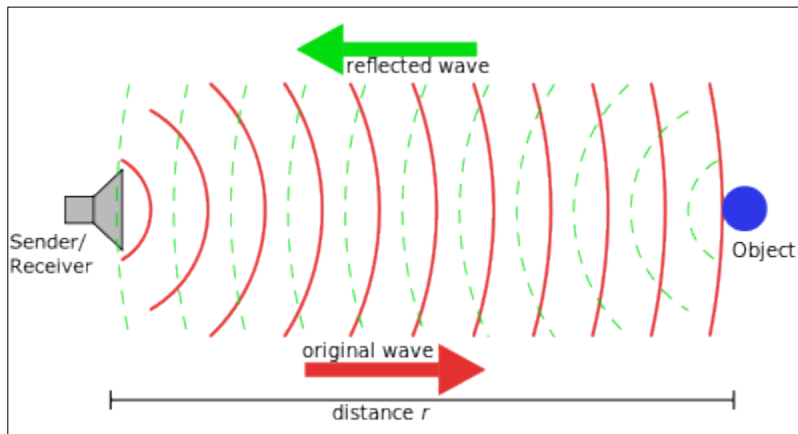


Figure 1- Principle of an active SONAR

(Source: <https://en.wikipedia.org/wiki/Sonar>).

These sensors are ideal for long range measurements. Although, normally these devices do not have good close-range measurements and their resolution can relatively be coarse.

3. Apparatus:

The sonar sensor on the mechatronic trainer is pictured in Figure 2. The voltage signal generated from the sonar sensor is proportional to the distance between the target and the sonar sensor. As the target moving away from the sonar sensor, the measured voltage increases.

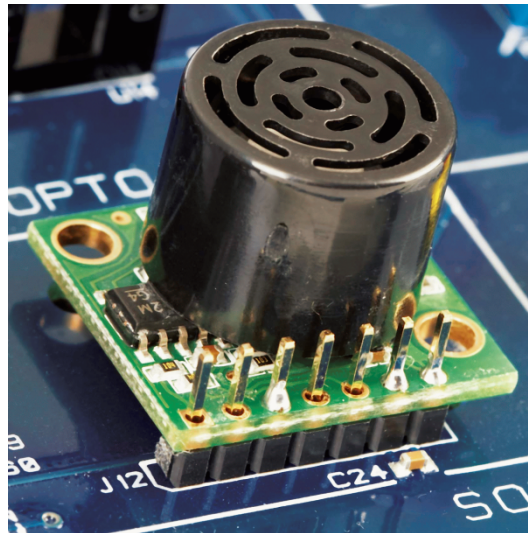


Figure 2-SONAR sensor on Qnet mechatronic sensors trainer

The virtual instrument used to collect data using the sonar sensor is shown in Figure 3. The instrument used to calibrate sonar range data is shown in Figure 4.

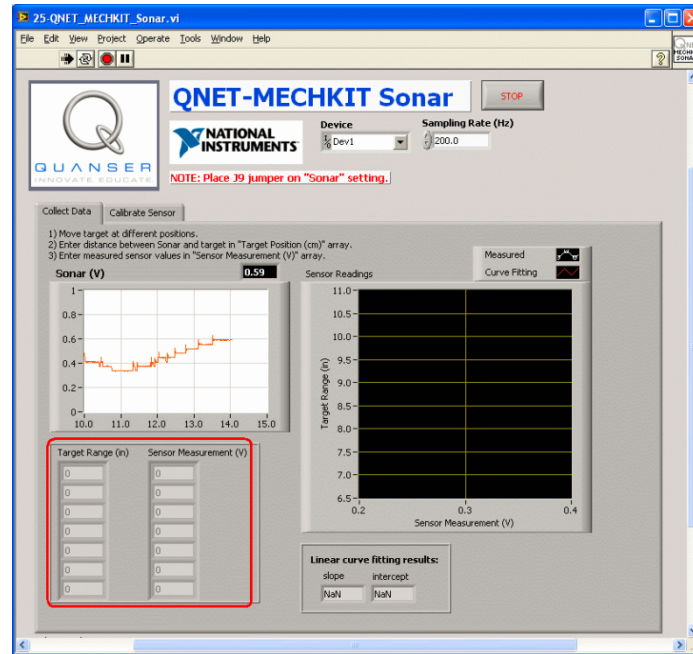


Figure 3-SONAR data collection

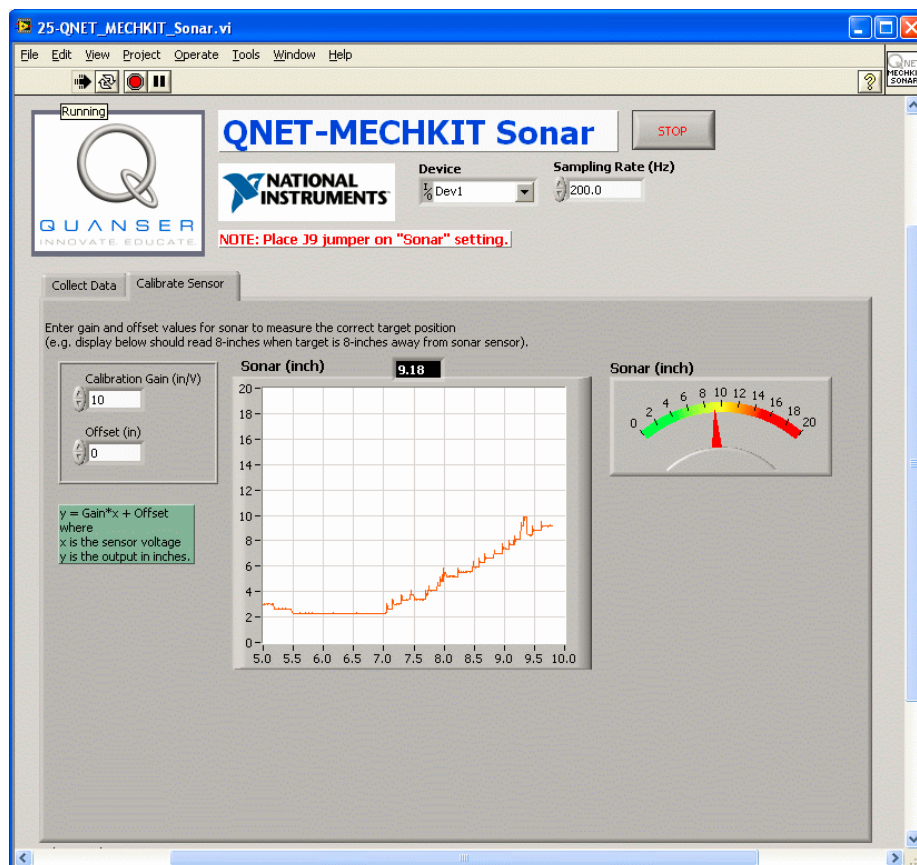


Figure 4-SONAR sensor calibration

Experimental Safety

- Wear proper safety gear I.e., shorts and open shoes are not allowed.
- Use rubber gloves when dealing with electric circuits.
- Do not spill any liquid in the premises of the apparatus.
- In case of spill, first turn off the circuit breaker then take out the plug before cleaning the spill.
- Do not touch or operate any equipment until you are instructed to do so.
- Follow the equipment operating manual.
- Note that the equipment must be GFI protected.
- Maintain a safe distance.

4. Procedure and calculations:

1. Make sure that J9 is set to Sonar.
2. Open the QNET_MECHKIT_Sonar.vi. Ensure that the correct Device is chosen.
3. Run QNET_MECHKIT_Sonar.vi.
4. To collect the experimental data, arrange a target e.g a sturdy piece of cardboard that is at least (10x10) *cm* with a reflective color like white or yellow.
5. Begin with the target close to the sonar sensor and slowly move it upward.
6. Once the lower end of its range of operation is found, enter the distance between the target and the sonar sensor in the Target Range (inch) array, as shown in Figure 3.
7. Enter the corresponding measured voltage from the sonar sensor in the Sensor Measurement (V) array, as shown in Figure 3.
8. Repeat for different target positions. Table 1 can be filled up. The sonar sensor is linear and the slope and intercept are generated and the fitted curve is automatically plotted.

Table 1-Collected data for SONAR sensor calibration

Target Range (in)	Sensor Measurement (V)
9	0.31
11	0.38
12	0.42
13.5	0.45
16	0.52
18	0.6
21	0.67

9. To calibrate sensor, select the **Calibrate Sensor** tab and enter Gain (in cm/V) and Offset (in cm) coefficients which are obtained from the previous steps. Make sure the coefficients are correct. When the target is 10.0 inches away, do the Sonar (inch) displays also show 10.0 inches? What is the difference between the actual position of the target and the displayed position calibrated by the sonar sensor? Change the target position at least 5 times to fill up Table 2.

Table 2 Comparison between the actual position of the target and the calculated position of the target.

Actual Target Position T (in)	Calculated Target Position T' (in)	Difference (T-T')
10	6.2	3.8
11	9.7	1.3
15	13.43	1.57
17.5	16.36	1.14
20.63	17.86	2.77

10. Click on Stop button to stop the VI.

5. Results and Discussion:

Should use EES for this lab

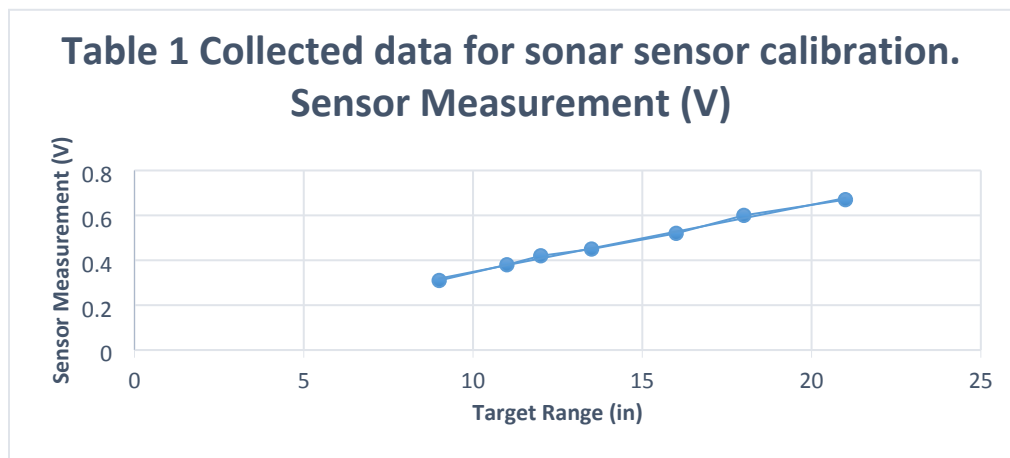


Figure 5- The linear plot of Target Rang and Sensor Measurement

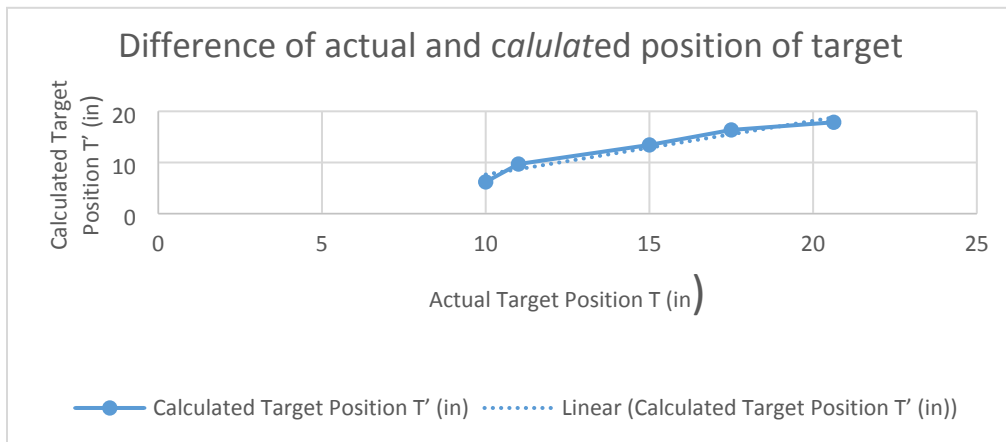


Figure 6-The linear plot of Actual Target position and calculated target position

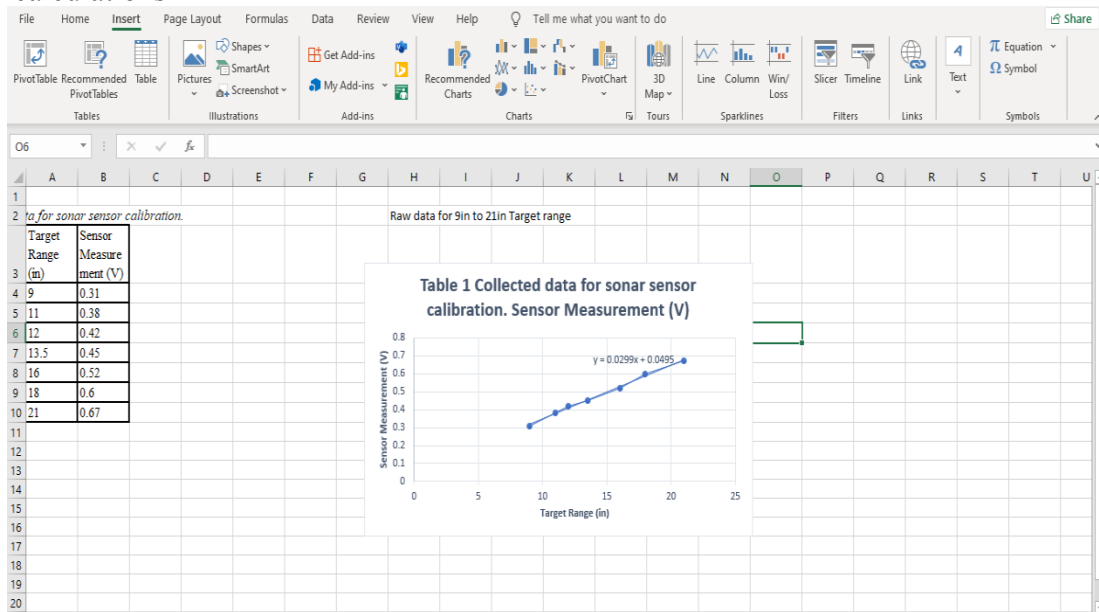
From the above results it is concluded that the data gathered in this lab demonstrate mostly linear relationships between Target Rang and Sensor Measurement along with other variables of measuring data during the experiment. As the target range increased it caused an increase in sensor measurement and the same trend was observed for actual target position and calculated target position.

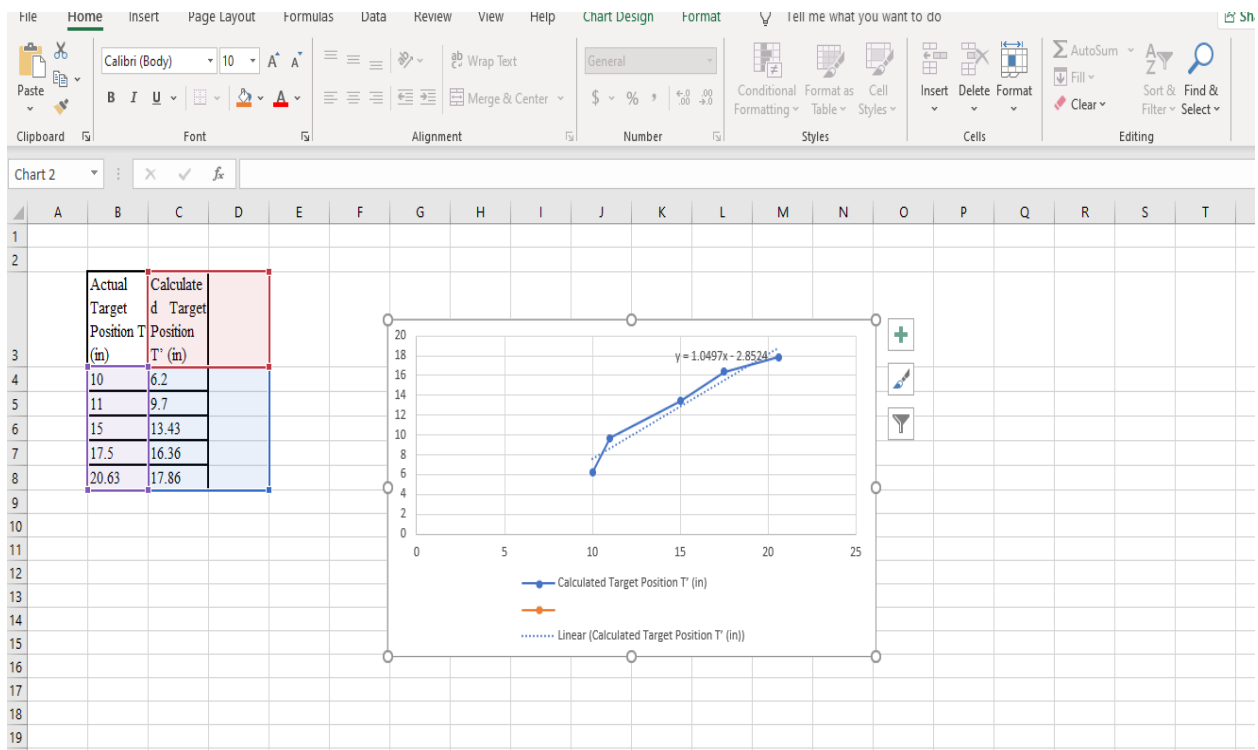
6. Conclusion:

It can be concluded that as the target object moved closer to the sonar sensor the sensor measurement increased. While there was a significant difference between actual target position and calculated target position by the apparatus with a percentage difference of 14.2%.

7. Appendices:

Excel calculations





**MEASUREMENT AND INSTRUMENTATION LABORATORY
FALL 2021**

Title of Assignment: LIFE-LONG LEARNING ASSIGNMENT 1

TOPICS COVERED IN LIFE-LONG LEARNING ASSIGNMENT

1. Engaging life-long learning activities

Life-long Learning Assignment

What is life-long learning and why?

A simple definition of lifelong learning is that it is “development after formal education: the continuing development of knowledge and skills that people experience after formal education and throughout their lives” (Encarta, [2008](#)).

The basic premise of lifelong learning is that it is not feasible to equip learners at school, college, or university with all the knowledge and skills they need to prosper throughout their lifetimes. Therefore, people will need continually to enhance their knowledge and skills, in order to address immediate problems and to participate in a process of continuous vocational and professional development. The new educational imperative is to empower people to manage their own learning in a variety of contexts throughout their lifetimes (Sharples, [2000](#), p. 178; see also Bentley, [1998](#)).

A life-long learning assignment

1. Go to the url: <https://academy.universal-robots.com/>, click ‘**Create Account**’
2. After login, go through Free E-learning -> e-Series e-Learning -> e-Series Core Track -> the **first 4** webinar modules
3. Take a screenshot with ‘completed’ status of the first 4 modules
4. Complete the questions in the next page
5. Put the **screenshot, questions and answers** into a word document
6. Upload the document on Canvas by **Tuesday, November 9, 2021**

MCEG3101 Measurement and Instrumentation Laboratory

Life-long Learning 1

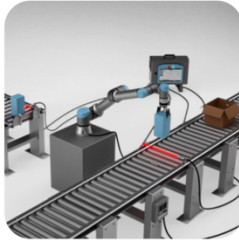
Student Name:

Grade:

1. How many axis does a Universal Robot have? Please list every joints. (12 points)
2. How can you set up a robot for a task? (18 points)
3. What is payload? (10 points)
4. What is a Tool Center Point and how can you find the Tool Center Point? (15 points)
5. What is a Center of Gravity and why you need to define it in the robotic software? (15 points)
6. Can the software calculate the TCP for you? How? (10 points)
7. When to calculate the orientation of a Tool? And how to calculate it? (20 points)

ABOVE AVERAGE

[← BACK TO OVERVIEW](#)



e-Series Core Track

The Core Track teaches all essential concepts, terminology and programming commands needed to operate a UR robot. The 8 modules are a step-by-step simulation of setting up and programming a complete pick-and-place application.



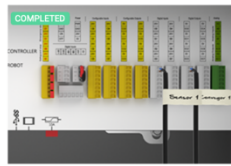
MODULES



1. FIRST LOOK: THE ROBOT AT A GLANCE

This module gives you a short introduction to the robot, user interface, I/Os and functions.

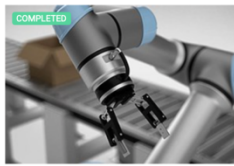
7m



2. PREPARING A ROBOT TASK

In this module, you will prepare the robot for a pick-and-place task by connecting an end-effector,...

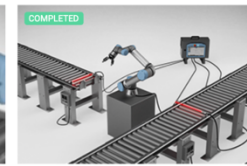
6m



3. SETTING UP A TOOL

Learn how to find and configure the tool center point, how to teach tool orientation, and how to tea...

17m



4. CREATING A PROGRAM

In this module you will learn about the robot's different motion types, and you will program all the...

12m

1. How many axis does a Universal Robot have? Please list every joints. (12 points)
It has 6 axes. The joints are: base, shoulder, elbow, wrist one, wrist two, wrist three

2. How can you set up a robot for a task? (18 points)

We can first attach the relevant tool to the tool flange, in this case that is the gripper. We then go to the teach pendant and go to installation, and go to I/O setup, we click tool out(0) and rename it to gripper. We go to tool io and set the tool output voltage, either 12V or 24V. We then go to the I/O section on the top and from here we can manually control the opening and closing of the gripper. After this we can attach the relevant sensors to the conveyor belts and attach them to the robots control box so robot know when it is time to pick the object up and when its time to place the object, and when its time to start and stop the conveyor. To rename the sensor, we go back to the teach pendant and form the top ribbon we choose installation, when then choose digital in(0) and rename it as sensor 1. We then rename digital out(0) to conveyor1. The robot can now sense when an object has reached the correct position on the conveyor and stop it.

3. What is payload? (10 points)

Payload is the weight of the end effector.

4. What is a Tool Center Point and how can you find the Tool Center Point? (15 points)

The tool center point is the distance from the end of the tool flange to the center between the point of contact between the tool and the object. We configure the tcp by first clicking the installation button in the top ribbon of the teach module then we click tcp, here we can enter the value manually in mm.

5. What is a Center of Gravity and why you need to define it in the robotic software? (15 points)

The center of gravity is the point on the tool where the weight is distributed evenly and we need

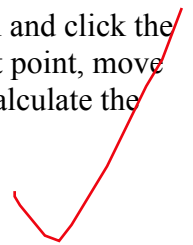
to define it because we need to know the center of gravity in order for the robot to correctly control the joint motors and carry out the task.

6. Can the software calculate the TCP for you? How? (10 points)

Yes the software can also calculate tcp for us. We can use the tcp wizard to have the robot learn the tcp. We go to the installation>tcp>tcp wizard and click set point 1, we move the robot to position one and we save the point by clicking ok, then we click point 2, move the robot to the same place from a different position and click ok. We do this until we have 4 points, the robots software can then calculate the tcp

7. When to calculate the orientation of a Tool? And how to calculate it? (20 points)

If the tool is not parallel with the z axis we need to set the orientation for the tool. Position tool parallel to z axis of the base. Go to the teach module>installation>tcp>orientation and click the drop down and select base since we want it in the direction of the z axis. Click set point, move the robot parallel to z axis and then click ok and then the set button. It will then calculate the orientation relative to the z axis.



AVERAGE

MCEG3101 Measurement and Instrumentation
Laboratory

87

Life-long Learning 1

Student Name: Kiron Buie Grade:

1. How many axis does a Universal Robot have? Please list every joints. (12 points)

6 axis: wrist1, wrist2, wrist3, shoulder, base, elbow

2. How can you set up a robot for a task? (18 points)

You use the teach pendant

3. What is payload? (10 points)

The weight of the tool

4. What is a Tool Center Point and how can you find the Tool Center Point? (15 points)

In the middle of where the robot and object come in contact, you find it after identifying the points of contact

5. What is a Center of Gravity and why you need to define it in the robotic software? (15 points)

When the tool is at a point where the weight is distributed evenly.

6. Can the software calculate the TCP for you? How? (10 points)

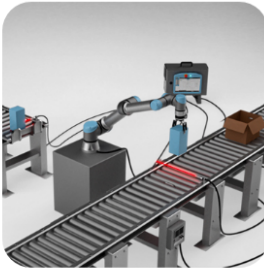
Yes, by aligning the z-axis and identifying the tool orientation

7. When to calculate the orientation of a Tool? And how to calculate it? (20 points)

When you have to find the TCP. Calculate by correctly positioning the robot with the tool aligning the z-axis then continue to move the robot into 4 separate locations to find the orientation



[← BACK TO OVERVIEW](#)



e-Series Core Track

The Core Track teaches all essential concepts, terminology and programming commands needed to operate a UR robot. The 8 modules are a step-by-step simulation of setting up and programming a complete pick-and-place application.

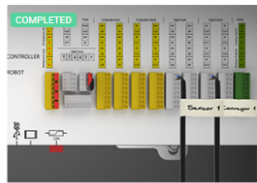


MODULES



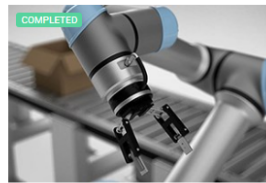
1. FIRST LOOK: THE ROBOT AT A GLANCE

This module gives you a short introduction to the robot, user interface, I/Os and functions.



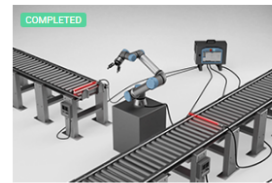
2. PREPARING A ROBOT TASK

In this module, you will prepare the robot for a pick-and-place task by connecting an end-effector...



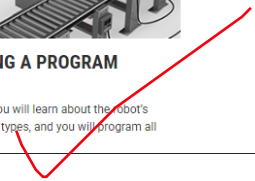
3. SETTING UP A TOOL

Learn how to find and configure the tool center point, how to teach tool orientation, and how to tea...



4. CREATING A PROGRAM

In this module you will learn about the robot's different motion types, and you will program all the...



BELOW AVERAGE

75

1. How many axis does a Universal Robot have? Please list every joints. (12 points)

Most industrial robots utilize **six axes**, which give them the ability to perform a wide variety of industrial tasks

2. How can you set up a robot for a task? (18 points)

A Universal Robot can be controlled from remote by sending simple commands to the GUI over a TCP/IP socket. This interface is called the "Dashboard Server". Main functions of the server are to load, play, pause, and stop a robot program, set user access level, and receive feedback about the robot state.

3. What is payload? (10 points)

The weight a robot arm can lift or a system that has mass that requires to be transported from point to point.

4. What is a Tool Center Point and how can you find the Tool Center Point? (15 points)

TCP is used to create necessary adjustments that allow the controller to shift the coordinate system to keep track of the tool instead of the arm's end.

5. What is a Center of Gravity and why do you need to define it in the robotic software? (15 points). The point from which the weight of a body or system may be considered to act. In uniform gravity, it is the same as the center of mass. It is critical for the robot arm when adding extensions and lifting materials

6. Can the software calculate the TCP for you? How? (10 points)

The software is used to find TCP when engaging in commands in the program.

7. When to calculate the orientation of a Tool? And how to calculate it? (20 points)

in 6-axis robotic arm is to pose diverse orientation. We need the orientation of a Tool to conduct task with accuracy and precision used in robot orientation. This is calculated in software automatically program utilizes kinematics equations in order to do computation.

MODULES



1. FIRST LOOK: THE ROBOT AT A GLANCE

This module gives you a short introduction to the robot, user interface, I/Os and functions.

7m



2. PREPARING A ROBOT TASK

In this module, you will prepare the robot for a pick-and-place task by connecting an end-effector,...

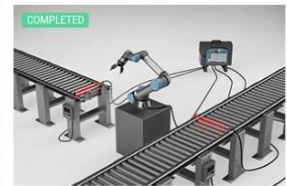
6m



3. SETTING UP A TOOL

Learn how to find and configure the tool center point, how to teach tool orientation, and how to tea...

17m



4. CREATING A PROGRAM

In this module you will learn about the robot's different motion types, and you will program all the...

12m



**MEASUREMENT AND INSTRUMENTATION LABORATORY
FALL 2021**

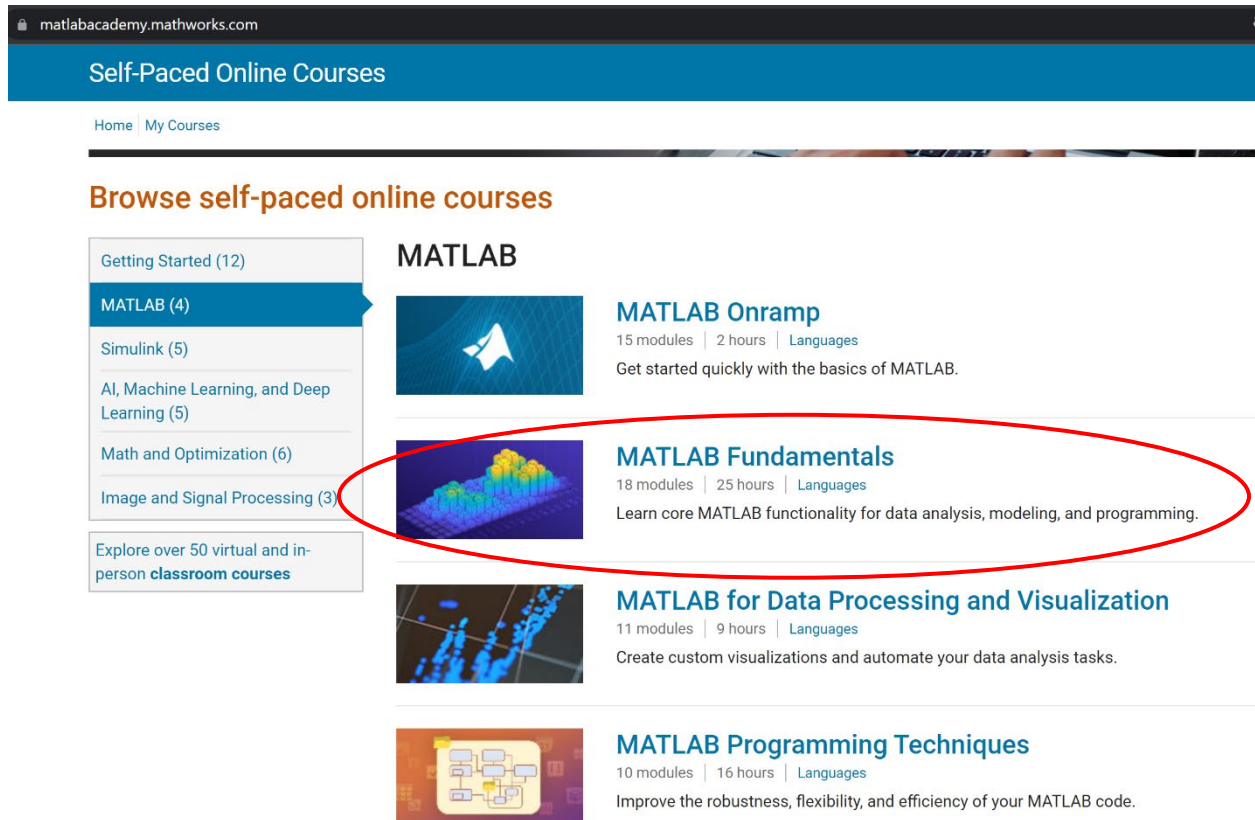
Title of Assignment: LIFE-LONG LEARNING ASSIGNMENT 2

TOPICS COVERED IN LIFE-LONG LEARNING ASSIGNMENT

1. Engaging life-long learning activities

Life-long Learning Assignment 2

1. Go to <https://matlabacademy.mathworks.com/>. Click on the “MATLAB for Data Processing and Visualization” course.



matlabacademy.mathworks.com

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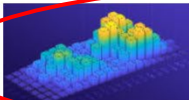
[Getting Started \(12\)](#)
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MATLAB



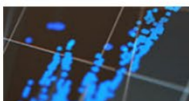
MATLAB Onramp

15 modules | 2 hours | [Languages](#)
Get started quickly with the basics of MATLAB.



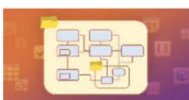
MATLAB Fundamentals

18 modules | 25 hours | [Languages](#)
Learn core MATLAB functionality for data analysis, modeling, and programming.



MATLAB for Data Processing and Visualization

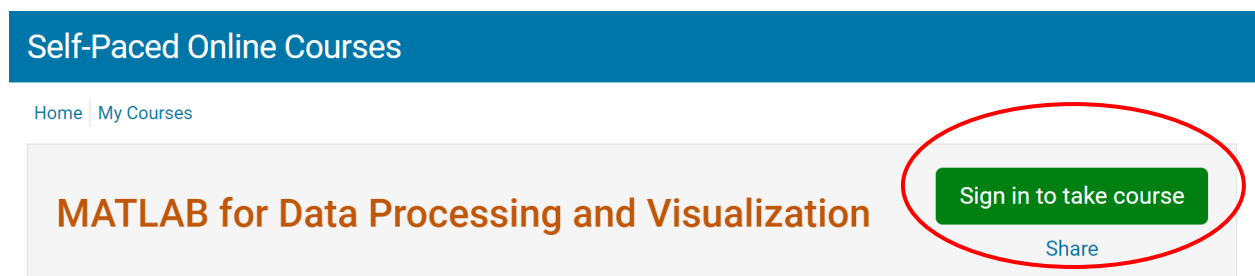
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Modules

[Course Quick Reference](#)

- [Getting Started](#) 30 min | 100%
- [Preprocessing Data](#) 50 min | 100%
- [Graphics Formatting Functions](#) 35 min | 100%
- [Review Project 1](#) 5 min | 100%
- [Importing Data from Multiple Files](#) 105 min

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Progress Report
Includes module details

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The correct url should look like the following:



Progress Report

Name: Chang Duan
Course: [MATLAB for Data Processing and Visualization](#)
Progress: 22% complete (as of 24 October 2021)

Chapters

1. Getting Started 100%
2. Preprocessing Data 100%
3. Graphics Formatting Functions 100%
4. Review Project 1 100%
5. Importing Data from Multiple Files 0%
6. Analyzing Groups within Data 0%
7. Customizing Graphics Objects 0%
8. Review Project 2 0%
9. Images and 3-D Surface Plots 0%
10. Importing Unstructured Data 0%
11. Conclusion 0%

Release: R2021a | Language: English

- 2 bonus points can be earned if you complete the whole course:

Your final average grade = final average grade based all your assignments (reports, exams, quizzes) + 2

ABOVE AVERAGE

Progress Report

Name: Joel Lewis
Course: [MATLAB for Data Processing and Visualization](#)
Progress: **100%** complete (as of 03 December 2021)

Chapters

1. Getting Started **100%**
2. Preprocessing Data **100%**
3. Graphics Formatting Functions **100%**
4. Review Project 1 **100%**
5. Importing Data from Multiple Files **100%**
6. Analyzing Groups within Data **100%**
7. Customizing Graphics Objects **100%**
8. Review Project 2 **100%**
9. Images and 3-D Surface Plots **100%**
10. Importing Unstructured Data **100%**
11. Conclusion **100%**

AVERAGE

Progress Report

Name: Heba Afzal

Course: [MATLAB for Data Processing and Visualization](#)

Progress: 22% complete (as of 23 November 2021)

Chapters

1. Getting Started 100%
2. Preprocessing Data 100%
3. Graphics Formatting Functions 100%
4. Review Project 1 100%
5. Importing Data from Multiple Files 0%
6. Analyzing Groups within Data 0%
7. Customizing Graphics Objects 0%
8. Review Project 2 0%
9. Images and 3-D Surface Plots 0%
10. Importing Unstructured Data 0%
11. Conclusion 0%

BELOW AVERAGE



Course Completion Certificate

Malaika Lee

has successfully completed **22%** of the self-paced training course

MATLAB for Data Processing and Visualization



DIRECTOR, TRAINING SERVICES

01 December 2021